Repair Mortar for a Coloured Layer of Sgraffito Render – A Technological Copy

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Abstract. Sgraffito technique was used to decorate renders by scratching the top layer of lime wash in the Renaissance time. In order to contribute to the preservation of surviving sgraffiti in the town of Slavonice in the Czech Republic a study was carried out assessing the possibility to replicate the original materials and the application techniques. Historical sgraffito layers were sampled in situ and studied in a laboratory by commonly used analytical methods - OM, TA, XRD, SEM-EDS. The raw materials, lime binder and sand, were characterised and the mixing proportion app. 1 to 0.7 (vol.) of lime putty to sand was determined. Based on the character of the local limestone, a similar raw material was obtained and burnt in an experimental lime kiln. The sand was obtained locally from a disused pit quarry. Obtaining the raw materials from similar sources as the historic ones allowed studying possible production technologies and application techniques. Appropriate and probable techniques were verified by a series of practical experiments. These considered: lime putty v. dry slaked hydrate; thickness of a layer; trowelling and final finishing; timing of drawing, scratching application of lime wash. The performance of the produced mortar mix was assessed by compressive and flexural strengths, capillary absorption, drying index, open porosity and water vapour diffusion coefficient. The mortar, designed as a material replica of the original, was used in a conservation project on a façade of a house, where missing parts of a sgraffito render were reconstructed.

Keywords: repair mortar · technological copy · sgraffito · limestone provenance · lime burning · production methods

1 Introduction

Historic mortars are characterised in order to describe their composition and physical properties in relation to design suitable repair procedures [1–3]. When a new repair mortar is designed, conservation professionals often advocate a "like for like" approach suggesting that the new mortar recipe should follow that of the original [4, 5]. From the analytical point of view, a copy based on composition is theoretically possible, but there is

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also a technological part that makes it quite a complicated task. Creating a technological copy of a work of art requires the use of the same materials and techniques that were used for the original.

In the historical centre of Slavonice, on the side facade of the house No. 545, there were found fragments of a Renaissance sgraffito with figures of Landsknechts. (A term used for mercenary soldiers in the period of the Renaissance in the territory administered by the Habsburg emperors. The term has a deeper meaning: a servant of the country fighting for Christian ideas.) The sgraffito used to be covered with a plaster, which protected it from the weather, and thanks to this protection, it has survived in an authentic state, which documents the original craftsmanship and art techniques. These sgraffito fragments offered an ideal opportunity to study the originally used materials and applied technologies. The subject of the research were the figural sgraffito fragments on the right side of the façade depicting a Landsknecht parade. Five figures have been preserved in their entirety, of the other two only fragments of their body (hand) and parts of armament (sword) have been preserved (Fig. 1).

Fig. 1. State before reconstruction of the facade with the Landsknechts. On both sides of the secondarily placed window there are fragments of the original Renaissance sgraffito. The sgraffito pattern on the left side of the picture belongs to the later Renaissance decoration.

Sgraffito, or "scratching" in render, or plaster, is usually defined as an engraved figural and ornamental decoration of the exteriors, and exceptionally of the interiors of buildings. The period in which sgraffito originates influences the character of artistic appearance and techniques. Sgraffito as a distinctive decorative technique, as found on the Renaissance facades in the Czech Republic, comes from the Italian Renaissance [6]. In the Renaissance, the authors of contemporary texts describe the sgraffito technique and point out its painting aspects, which consist of shading. Girogio Vasari (1511–1574) and Filippo Baldinucci (1625–1696) describe details of a technique called "scraping on facades" such as hatching (*tratteggiare*), "pushing" (*aggravare*) and adding "light shadow" (*chiari e scuri*) or "semi-coloured" (*mezzo colore, tinta di mezzo*), which is clearly a description of shading [7]. Both authors also suggest a further colouring or supporting of shadows with watercolour as part of the technique [7] (Fig. 2). Most

Renaissance sgraffiti in the Czech Republic consist of only one fine-grained mortar layer, called *intonaco* in Italian terminology, with a lime wash on the surface [8]. When the texture of this render is revealed by scraping, the colour of the base becomes apparent. Italian contemporary terminology refers to black intonaco (*intonaco nero*), coloured with charcoal. However, the base mortar most commonly has a colour of a filler, which is than simply called a coloured layer/intonaco.

Fig. 2. Detail showing three basic surface finishing techniques of the sgraffito. In the upper third, the lime wash is untreated and this finish acts as the brightest one, in the middle third, the lime wash is partially removed and smoothed with a spatula. This surface was subsequently decorated with hatching. The darkest part at the bottom was created by completely scraping away the lime wash and partially also the mortar surface.

2 Original Sgraffito Technique

The intention of the restoration of the sgraffito was that, if the appropriate graphic originals could be found, the figures would be completed and the fragments could be perceived as more complete scene. The original parts were to be conserved based on the principle of minimal intervention. The newly reconstructed parts of the sgraffito were to be made as a material and technological copy of the original, while maintaining the differences between the reconstructions and the original. By comparing the original Landsknecht figures traced on transparent plastic sheets with a large number of contemporary illustrations, it was found that the prints from the digital collection of the Herzog-Anton-Ulrich Museum in Braunschweig corresponded best to them. However, the Erhard Schön's original illustrations for Hans Sachs's poems about the Landsknechts had to be adapted to the scale of the surviving fragments of sgraffito figures.

2.1 Material Characterisation

The survey investigated the material composition and layering of sgraffito. The parameters assessed and the methods used are summarized in Table 1.

Table 1. Analytical procedures used in the study of the Landsknecht sgraffito mortar system and the summary of the analytical results based on samples.

Thickness of layers and their composition Methods used: *in-situ* survey, OM	The studied sgraffito consists of three layers: an underlying background layer, a 5–10 mm thick coloured intonaco and a 0.3–0.6 mm thick lime wash coating. The intonaco is sound and contains only lime and sand with no other colouring additives (Fig. 3). The lime wash does not contain any filler, only isolated binder related particles up to 0.4 mm in size. The lime wash is a single coat, no application sublayers were detected. A good bond between the lime wash and the substrate is probably due to fresh-on-fresh application. The surface area of the lime wash is enriched with the binder. The lime wash shows brush stroke-marks and different variations of thinning and smoothing down to the substrate
Characteristics of the binder Methods used: OM, SEM-EDS, TA, XRD	The same or very similar calcitic binder was used for both the coloured layer and the lime wash (Figs. 4 and 5). The coloured layer contains macroscopically visible light-coloured binder related particles up to a size of 4 mm. They are mainly composed of partially burnt binder related particles formed by imperfect slaking or during mortar preparation. There are also calcium silicate particles (lesser extent) and their composition differs from the binding matrix. These are very probably relics of silicate minerals from the original raw material, crystalline limestone. These particles potentially add hydraulicity to the binder
Characteristics of the agg Methods used: OM, SEM-EDS Sieve analysis	The aggregate of the coloured layer consists of sand with majority of quartz and gneiss, feldspars and light and dark micas. The particles are unworked, sharp-angled, with an uneven surface. This indicates a short transport or formation by in situ weathering. The sand is less than 4 mm in size, the fraction under 0.063 mm is up to 5 wt. %. The sand was probably treated by sieving. There was no evidence of organic admixtures
Binder to aggregate ratio Methods used: AD, OM	The mortar is riche in binder. The mass ratio of the soluble component to the insoluble component in the coloured intonaco is 37.3: 62.7. The gauging proportions calculated for the materials used to make the trial panels and the technological copy are summarised in Tables 2 and 3
Organic additives Methods used: OM, GC-MS, IR, TA	Traces of the milk protein (casein) were detected in the lime wash in sample OSLB 4 using nanoliquid chromatography. This finding was not confirmed in the other samples and its presence was not identified by IR. The same sample also contained calcium oxalate. It was detected by TA and IR only in this sample. Its presence was interpreted as a result of the action to biological growth (Fig. 4)

**OM – optical microscopy; SEM-EDS – scanning electron microscopy; TA - thermal analysis; XRD - x-ray powder diffraction; AD - acid dissolution; GC-MS - liquid chromatography with mass spectrometer; IR - infrared spectroscopy; CI - cementation index.*

Fig. 3. The coloured intonaco layer is composed of fine-grained binder with occasional binder related particles and an aggregate - predominantly quartz and gneiss. The lime wash does not contain filler and appears as one about 0.2–0.4 mm thick single layer. Sample OSL 4, PPL.

Table 2. Gauging proportions of lime and sand base on acid dissolution test.

	Soluble v. insoluble ratio	Binder - lime putty	Binder – hydrated lime powder	Binder – lump quicklime
	Content [wt.%]	Vol. ratio	Vol. ratio	Vol. ratio
Binder	37.3	1.0	1.0	1.0
Sand	62.7	0.7	0.9	1.4

Table 3. Properties of lime binder (Nedvědice quarry) and aggregate (Slavonice quarry) used to convert mass to volumetric proportions.

	Bulk density [kg/m^3]	Dry matter [hm. %]
Lime putty	1350	40
Powder hydrate	740	
Lump quicklime	850	
Sand	1850	

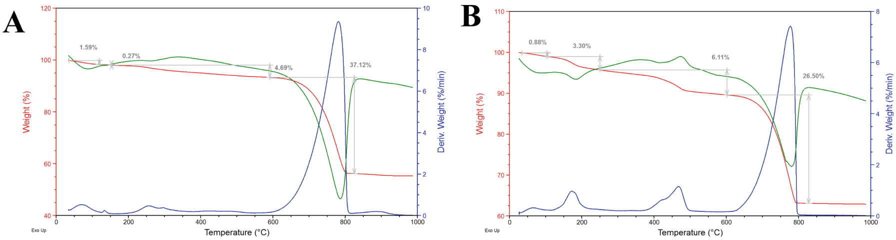
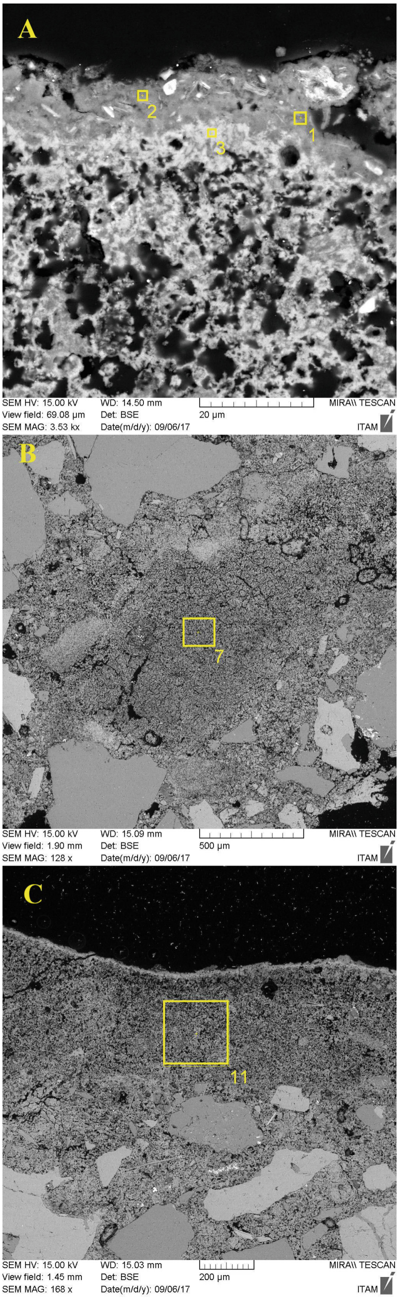


Fig. 4. TA analysis of a binder related particle from the coloured intonaco from the OSL 3 sample (A) and from the OSL 4 sample (B). Beside the carbonate decomposition band, there are two bands corresponding to the contamination of the OSL 3 sample by calcium oxalate.



	LW 11	LW 3	LW 1	LW BRP 2	I BRE 7	I M 9
CaO	96.1	97.3	84.2	53.3	97.0	15.0
SiO_2	1.1	0.7	7.2	43.4	1.6	50.7
Al_2O_3	0.1	-	3.9	1.1	-	2.1
MgO	1.6	1.1	1.8	0.9	1.4	30.1
Na_2O	-	-	0.4	0.5	-	-
K_2O	-	-	0.6	0.5	-	0.2
P_2O_5	-	0.3	0.4	-	-	0.5
SO_3	0.7	0.6	0.3	-	-	1.0
Cl	0.4	-	0.3	0.4	-	-
FeO	-	-	1.1	-	-	0.4
Total	100	100	100	100	100	100
CI	0.03	0.02	0.28	2.25	0.04	-

LW – lime wash; M – binding matrix and small binder particles; BRP – binder related particle; I – coloured intonaco layer; CI – cementation index category: 0–0.3 air lime; 0.3–0.5 feebly hydraulic lime; 0.5–0.7 moderately hydraulic lime; 0.7–1.1 eminently hydraulic lime; > 1.1 natural / roman cement.

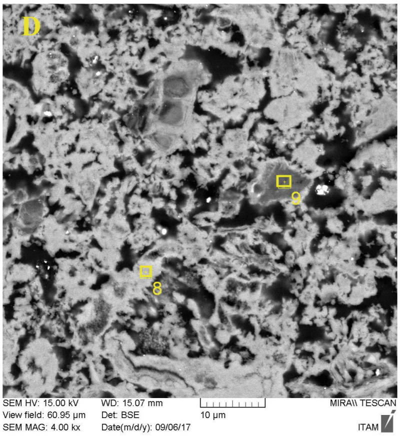


Fig. 5. Surface of lime wash with contamination (A). A binder cluster in the coloured intonaco layer (B). Lime wash and coloured intonaco layer (C). The lime wash is well bonded with the background, no individual sub-layers are visible in the lime wash coating. Matrix of coloured intonaco with small binder particles varying in composition (D). Sample OSL 4, SEM – BSE. The table present the EDS analysis of the binding matrix and the binder related particles.

3 Design of a Repair Mortar for Coloured Intonaco Layer as a Material Copy

3.1 Lime

The town of Slavonice is located in the Moldanubic area with magmatic and metamorphosed rocks, including crystalline limestone or marbles. Knowledge of the local geology suggests that crystalline limestone was very likely the raw material used for the lime production, which is in line with the findings of the material analysis. In the search for a suitable raw material, several historic limestone quarries in the area were explored [9]. The nearest possible sources could not be used for various reasons (abandoned quarries were mostly backfilled). The quarry in Municipal Quarry in Nedvědice is about 120 km away but is located in the same geological formation, and sufficient quantities of good quality stone can still be found there. This raw material fulfilled the basic material characteristics determined by the analysis of the binder and was the most readily available of the identified historic quarries. It is a crystalline limestone with calcium-silicate admixtures, clasts of which were present in the mortar binder and in the lime wash coating. The chemical composition of the samples taken on the spot indicated a raw material suitable for the production of air lime (cementation index $< 0,3$; $CaCO_3$ content $> 94\%$), which was also confirmed by the XRD analysis of the raw material and the burnt quicklime samples, see Table 4.

Table 4. XRD quantitative phase analysis of the raw material (white marble) and three quicklime samples of white Nedvědice marble burnt at 1050 °C with residence times 3 h, 5 h and 8 h.

	NB Raw material	NB_3h	NB_5h	NB_8h
Calcite	94.7			
Lime		62.5	57	61.9
Dolomite				0.3
Portlandite		3.5	7.1	4.5
Periclase				0.1
K-feldspar	0.8		1.3	0.3
Mica	1.4			
Clinopyroxene		1.5		0.9
Diopside	3.0			
Amorphous	n.d	32	34	32

3.2 Sand

In the vicinity of Slavonice, there are eluvial deposits of gneiss massif. The sand is dominated by sharp-angled quartz particles, gneiss, light and dark micas. Samples taken from extinct sand pits in several places near Slavonice corresponded in their mineralogical composition to the sand used in the Slavonice sgraffito. Apart from the regional affiliation, the selection of suitable sand took into account grain size distribution and mineralogical composition, as well as the proportion of fine and clay particles. The workability of mortar, its colour and the appearance of the sgraffito lines and surface finishes were also crucial in the evaluation. In terms of colour and plasticity, the mortar made with sand that had the lowest content of the finest fraction among the sands from the local pits was the most suitable. The granulometric curve of this sand also corresponded best to the original, both in the amount of fine fraction and in the majority of the 0.5–1 mm fraction. This sand from the now abandoned sandpit in Slavonice was chosen as a suitable one (Fig. 6). It contained a very small amount of organic particles and therefore did not need to be cleaned by washing, only the max. Grain size was limited by sieving. The content of Cl^-, NO^{2-}, $SO_4{}^{2-}$ anions was check and was found to be low.

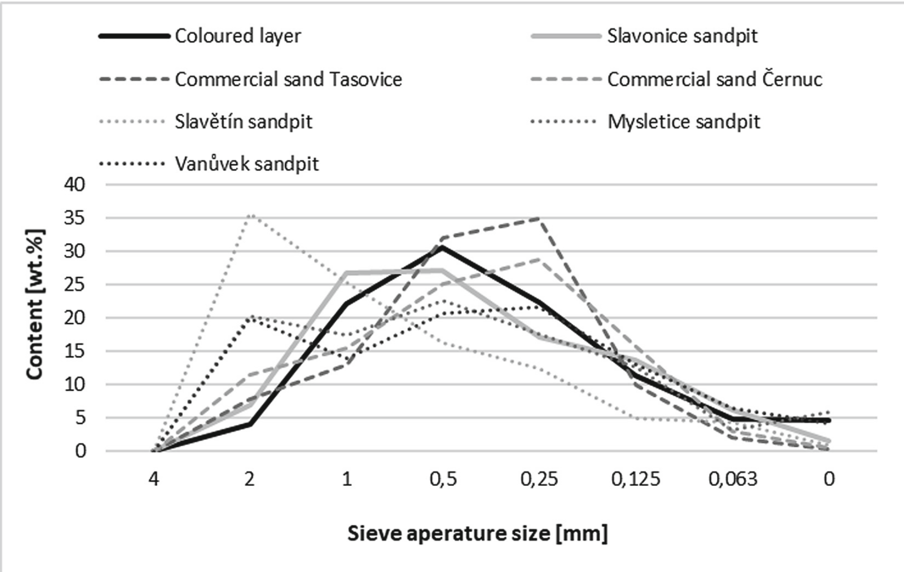


Fig. 6. Comparison of the sand used in the coloured intonaco layer with the samples from Slavonice sandpit, two commercially available sands and other local sandpits.

3.3 Production and Processing Technologies

The aim was to produce a mortar that replicated the original in as many details as possible. The selected raw material was burnt in a wood-fired flare lime kiln according to a procedure that reflected the traditional lime burning in the area [10]. By calcining the Nedvědice marble, we obtained quicklime in lumps, whose further processing had to be decided. The texture of the original coloured intonaco layer contains white "lime particles", which are sometimes clearly visible on the scraped surfaces of the original sgraffito. This led to a suggestion that lime was dry slaked to powder before its use as a binder. This idea was supported by the fact, that the present lime-based particles were limited in size to 4 mm and smaller as if the binder was sieved through the same sieve as the sand. After practical tests and taking into account the above-mentioned aspects, the lime intended for the preparation of the coloured intonaco was dry-slaked to powder. A traditional way was followed, when the quicklime is immersed in a basket for about 15 s to water and then it is left to slake on a heap [11]. After slaking, the grain size was then adjusted by sieving to obtain particles below 4 mm. For the lime wash, the quicklime was slaked in excess water in a wooden slaking vessel. The hydrated lime and the putty were prepared two weeks prior to use, ensuring that all binder particles had enough time to react with water. The intonaco mortar was prepared from lime and sand in a vol. ratio 1:1.

4 Assessment of Physical Properties of the Material Copy

The anticipated advantage of using a technological replica of the original mortar is the guarantee that it will appropriately complement the existing historic materials. An inappropriate material addition could result in a shortened life span of the original or even in accelerated degradation. To assess the copy of the intonaco, its mechanical and physical properties were determined on laboratory specimens according to EN standards. The testing procedure is published elsewhere [12]. Mortar testing was conducted in two sets of different consistencies (initial water contents). The mortar properties obtained were compared with some published values for lime-based mortars, see Table 5. The strength of the intonaco replica is higher than the predicted strength for air lime mortar. The determined strengths correspond to a weakly hydraulic lime, category NHL 2. The capillary absorption, drying rate and water vapour permeability are also consistent with NHL mortars. The open porosity is slightly higher than the values published for naturally hydraulic lime mortars.

SEM analysis of a sample taken from a replicated sgraffito showed an increased level of various mineral relicts with reaction rims compared to the original mortar (Fig. 7). The composition of lime wash was similar to the original. The heavier particles probably sedimented when the putty was left to rest and were not present in the paint.

5 Practical Use and Evaluation by Experiments

The designed mortar was tested on trial panels in order to assess its properties and practical suitability for application in the proposed restoration. The following parameters were considered: workability and plasticity, the speed of setting in relation to the quality of sgraffito drawing, and last but not least, the final appearance and its surface texture. In practical tests, it was necessary to maintain similar layer thicknesses as on the original for both the coloured intonaco and the lime wash. During the tests, the timing of the individual steps was assessed; e.g., sufficient setting of the coloured intonaco for the application of the lime wash, the optimum state of the lime wash paint for the sgraffito drawing and shading; the presence of shrinkage cracks. The first practical tests took place outside the building itself. Once the technological procedure had been refined,

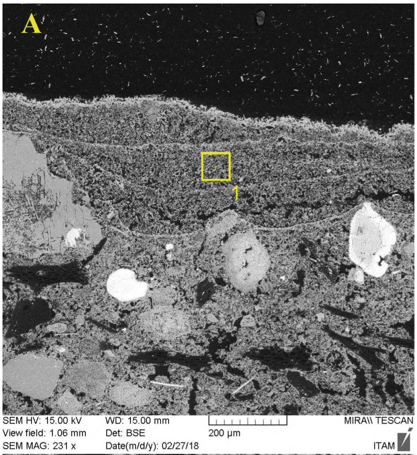
Table 5. Characteristic values of the designed mortar compared with published values. The properties were determined after 120 days of curing on standardized specimens (40 mm × 40 mm × 160 mm). B: A = binder: filler.

	Designed mortar		Reference mortars from literature	
Water content	29 wt. %	26 wt. %	Hydraulic limes (NHL)	Air limes (AL)
Compressive Strength [MPa]	5.9 ± 0.4	6.8 ± 0.3	7.5–10.5 (B:A 1:1 vol.) after 180 days [13]	3.5–4.2 (B:A 1:1 vol.) after 1 year [14]
Flexural strength [MPa]	3.0 ± 0.1	3.3 ± 0.3	1.2–2.5 (B:A 1:1 vol.) after 180 days [13]	0.9–1.1 (B:A 1:1 vol.) after 1 year [14]
Capillary absorption Cc 10´–2´ [$kg.m^{-2}.h^{-1/2}$]	6.61 ± 0.33	5.73 ± 0.36	5.64 (B:A 1:3 vol.) after 3 years [15]	8.34 (B:A 1:3 vol..) after 3 years [15]
Drying index [−]	0.196 ± 0.004	0.179 ± 0.016	0.139–0.417 (B:A 1:3 vol.) after 3 years [15]	0.168 (B:A 1:3 vol.) after 3 years [15]
Total open porosity [vol. %]	35.7 ± 0.4	34,5 ± 0.2	28.0–30.0 (B:A 1:1 vol.) after 1 year [13]	24.1–27.1 (B:A 1:1 vol.) after 1 year [13]
Water vapour diffusion coefficient μ [−]	10.1 ± 2.1	11.5 ± 2.5	11.1–17.5 after 3 years [15]	23.3 after 3 years [15]

further tests were carried out on site, which allowed the timing of the individual steps in accordance with the local conditions. The choice of sand was verified on site in relation to the original mortar appearance. Its colour and effect on the drawing pattern were assessed, and the tendency to crack at different thicknesses of coloured intonaco was noted and evaluated.

The following practical conclusions regarding the application technique were drawn:

- The choice of processing lime to a powdered hydrate proved as practical as there were fewer cracks compared to mortars made with putty. The local sand from the Slavonice sandpit was also suitable in terms of the required colour and the fineness of drawing.
- The mortar should be prepared at least four days in advance to ensure the completion of the slaking process.



	LW	I					
		M	BRP	BRP	MR	RC	M
	1	2	3	4	7	8	9
CaO	97.6	62.9	98.4	98.4	-	69.2	94.0
SiO_2	1.8	31.0	1.6	1.1	100	30.8	5.7
Al_2O_3	0.1	0.1	-	-	-	-	0.3
MgO	0.5	6.0	-	0.5	-	-	-
Total	100	100	100	100	100	100	100

LW – lime wash; I – coloured layer; M – binding matrix and small binder particles; BRP – binder related particle; MR – mineral relict, RC – reaction rim.

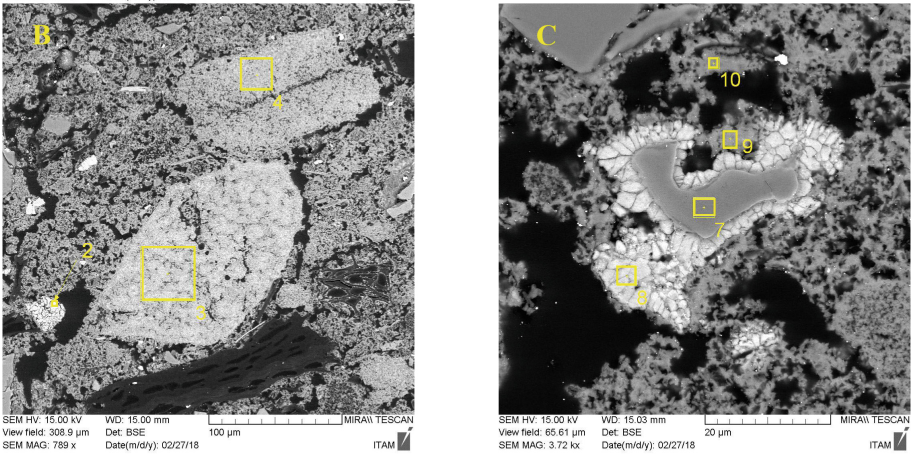


Fig. 7. Replicated sgraffito. Lime wash applied in three coats (A). Binder related particles of various composition in the replicated coloured intonaco (B). A mineral relict with reaction rim and the surrounding binding matrix in the replicated coloured intonaco (C). Sample SGSLU, SEM – BSE. The table present the EDS analysis of the binding matrix and the binder related particles.

- It was confirmed that the analytically determined proportions of powdered hydrate to sand in a volume ratio of 1:1 were suitable for the coloured intonaco. The lime-rich mixture had good water retention and the desired thickness was achieved with a minimum of cracking.
- The absorption capacity of the substrate significantly influenced the timing of the sgraffito application procedure. Adequate pre-wetting of the substrate allowed the speed of the process to be controlled. In parallel, the climatic conditions must be taken into account during the application process.
- Due to the tendency to crack, it is better to apply the mortar in two layers. It seems that the first layer is preferable to be slightly thinner as it then adheres better to absorbent rough substrate.

- Lime wash is prepared from lime putty diluted by water. The thinning of the paint corresponded to the degree of intonaco setting, masonry absorption capacity and weather conditions. It is desirable to apply it only after the primary drying cracks of the coloured layer appear and are sealed. The drying cracks were evident in all tests and, if pushed back at the right time, they did not further appear.
- It is preferable to apply the lime wash in several coats with minimum time intervals, however, the bottom coat must be set before application of the next layer.
- During the reconstruction of the sgraffito, it is desirable to apply the paint with a brush at the moment when the surface does not react to the fingerprint of the hand and therefore the paint does not mix with it. The first coat should be thinner, as with the coloured intonaco, so that it blends well with the substrate. A thicker coat can be applied in the next layer.

The findings related to the sgraffito technique itself, as well as the restoration procedures, are not discussed here in details but can be found elsewhere [16, 17]. The restoration project was successfully completed. The new sgraffito parts were slightly retouched with pigments from the local sand to reduce the contrast between the old and new areas (Fig. 8).

Fig. 8. The reconstructed sgraffito facade after two years. Slavonice, house No. 545.

6 Concluding Remarks

The article presents the procedure used to create a technological copy of a Renaissance sgraffito. This procedure combined several sub-tasks related to the analysis of historic sgraffito and the interpretation of the analytical results for building conservation practice. This holistic approach, which links the quality of the material with the craftsmanship and final appearance of the sgraffito, proved to be an interesting way to deepen the understanding of these topics, which are often studied independently.

In terms of technology, there are some points which should be assessed further in future. Dry slaked lime to powder hydrate was used as there were binder related particles found in the historic mortar. Slaking lime to putty did not provide so many binder related particles. The use of powder hydrate allowed for better workability adjustment of mortar. The water content of lime putty is typically around 50% by weight or more, which makes the lime-rich mortar too thin and runny. Reducing water content in lime putty mortars is possible, for example by drying or mechanical squeezing, but in our case, this seemed less practical.

The dry slaked lime had a higher heterogeneity in particle size than the currently available standard commercial limes would have. This affected the workability of the mortar. The larger particle size of lime, up to 4 mm according to the original, also meant a higher proportion of binder in determining the binder to sand ratio. The gauging ratio, if calculated based on the dissolution of the mortar in acid, should ideally also be related to the size distribution of the binder particles. However, as this is not practically possible, a minimum knowledge of the raw materials used and the differences between lime production technologies in the past and today is necessary. The current EN 459-1 standard requires at least 85% (wt.) particles to pass a 90 μm sieve. Historical technologies very probably produced coarser particles. Replicating the technological processes of the past could provide binders comparable to historical ones.

TA and SEM-EDS analyses of the binder indicated that a relatively pure lime was used to produce the original mortar. This resulted in a search for a calcitic marble with a high calcium carbonate content. A suitable source of raw material was found and the marble was burnt in a wood-fired kiln in a manner that would have been consistent with the 16th century in then Bohemia. However, it was found later, when the mechanical properties were assessed, that the mortar made from this lime had parameters comparable to natural hydraulic limes. The XRD of quicklime did not show presence of any typical hydraulic phases such as C_2S [18], nor any quartz relicts, probably due to the fact, that the analysed samples were not fully representative of the whole batch. The SEM-EDS analysis of the replicated mortar revealed a number of calcium-silicate particles and quartz particles with reaction rims. It is possible that the localized calcium-silicate impurities in marbles reacted and were activated at high temperatures during calcination (900–1200 °C) and subsequently caused the formation of hydraulic bonds in the mortar. This could have been the case also of the historical mortar, but the determination of hydrated hydraulic phases in historic mortars is quite a complex task, especially when they are exposed to moisture cycles and their carbonation is promoted over a long time [19, 20].

Knowledge of the technological processes of lime production and mortar preparation cannot be obtained by studying samples alone. Here, an approach was chosen which consisted in combining the findings from historical samples based on laboratory analyses with possible technological processes, which were then verified by practical experiments. Such a procedure led to new insights in the field of the original Renaissance sgraffito techniques. Finally, it was thus possible to apply these materials in the reconstruction carried out to complete the missing parts of the Landsknecht figures. The historical sgraffito was conserved, the additions were realised as a technological copy.

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