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Characterisation of Roman and Mediaeval renderings. The case of the remains found in archaeological excavations in the city of Valencia (Spain)

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ABSTRACT

Since antiquity man has rendered the interior and exterior of the spaces he has built and inhabited. The detailed analysis of samples of rendering from the Roman and Mediaeval period makes it possible to further explore the techniques used in their execution, in addition to comparing the built fabric and the knowledge presented in treatises. The samples analysed from archaeological excavations in the city of Valencia make it possible to define continuity features between the rendered constructions, especially Roman and Mediaeval interiors, and the characteristics of residential buildings in the city constructed or transformed in the 18th, 19th and early 20th centuries. This article includes the results of the analysis and testing of the characteristics of a total of ten samples of historic renderings from the Roman (5), Islamic (4) and Mudejar periods (1). This eventually led to a morphological, physical–chemical and chemical–mineralogical study of 17 different mortars. However, the remains analysed were not the only source consulted. A detailed historical study based on several bibliographical sources and specific fiches also uncovered interesting aspects of its material and construction. In addition, the information obtained was analysed both globally and individually, establishing relations between different archaeological samples and the renderings of the historic façades of the city, thus revealing important aspects of the technical and material evolution of the continuous renderings in the city of Valencia.

1. Introduction

Since antiquity man has rendered his dwellings both inside and out. This answers aesthetic needs as well as the protection of different fabrics in mud, reeds and other materials requiring a surface finish to ensure weather resistance. Continuous mortar or paste renderings have therefore been used by almost all civilisations or cultures, developing techniques with different degrees of complexity and adapting them to the tastes of each period.

The case of the historic centre of Valencia is no exception. At present, most of the exterior rendering of residential buildings, mainly dating back to the 18th, 19th and early 20th centuries, consists of one or several layers of mortar or paste. This unique feature has prompted detailed research on the surface renderings which currently protect and decorate the historic façades (La Spina, 2015; La Spina et al., 2013a; La Spina et al., 2013b). However, further research was also considered necessary on the chronology of rendering, as well as on the technical and material characteristics of rendering in Valencia from the foundation of the Roman city in 138 BC until approximately the late Middle Ages. Most of this study results from the scientific analysis of archaeological remains of rendering found in the city and the search for specific information in bibliographical texts and references.

2. Research methodology and phases

The methodology followed and the different research phases were defined at all times by both theoretical and practical aspects. The deductive method used combined historic research and specific scientific study. Thus, the first phase of the research consisted in the bibliographical search through general and individual documents on renderings and Valencia for any information that could provide a historical context. In this respect, publications on the history of the city were crucial (Dauksis Ortolá and Taberner Pastor, 2000; Dauksis Ortolá and Taberner Pastor, 2002; Alonso Monterde et al., 2004 and Alonso Monterde et al., 2008), as were the different historic architectural treatises including that by Vitruvius, who dedicates most of the seventh book, and more specifically the third chapter, to explaining how to execute a rendering (Vitruvio Polión, 1787). However, given the fairly general nature of the information obtained, the second phase of the research consisted in a scientific study, similar to other studies carried out (Crisci et al., 2004; Torraca et al., 2003; Pecchioni et al., 2008; Pecchioni et al., 2014; Blasco et al., 2013), aiming to obtain specific

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Fig. 1. Images of the samples analysed: RO-01, RO-02, RO-03, RO-04, RO-05, IS-01, IS-02, IS-03, IS-04, MU-01.

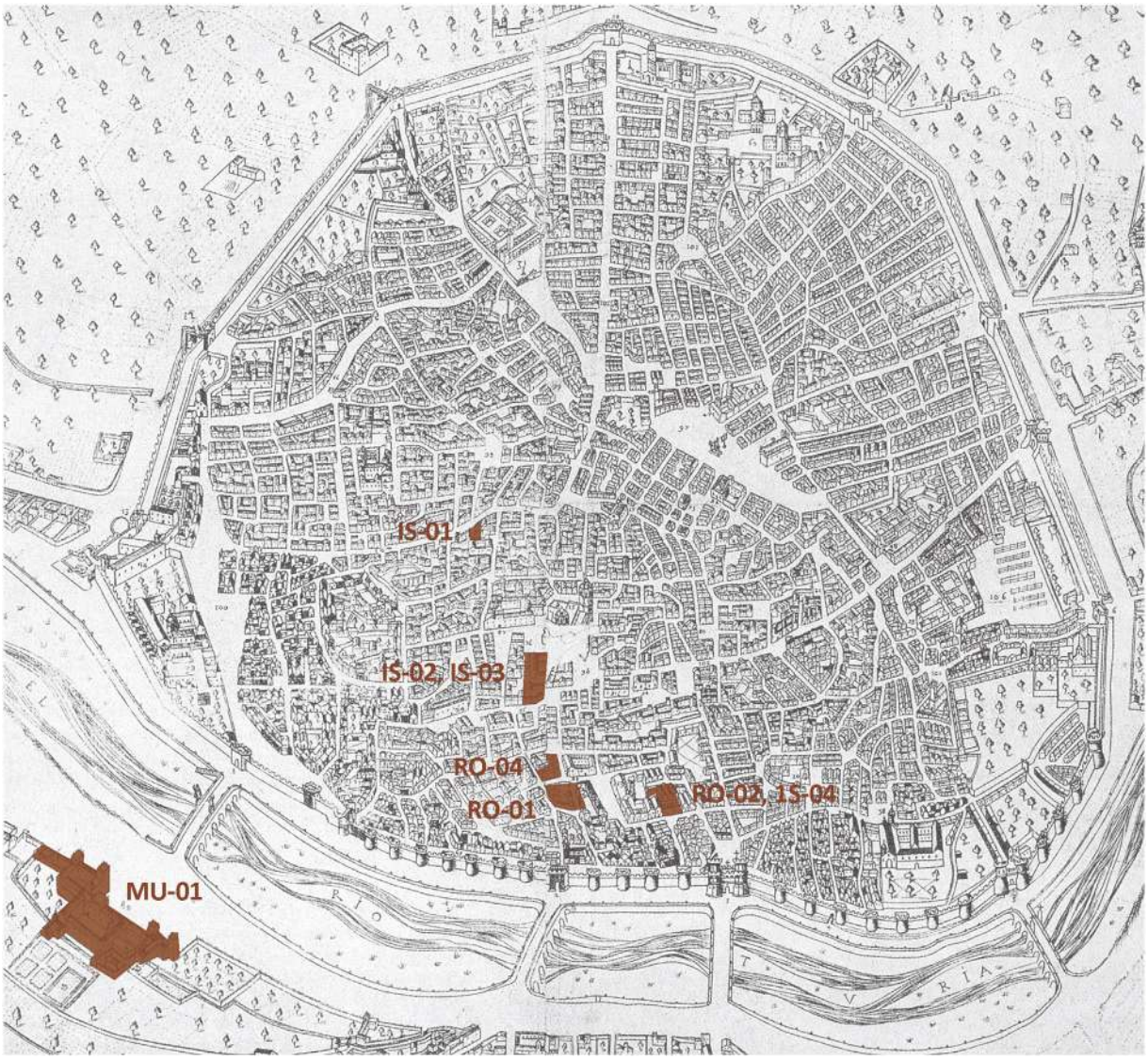

Fig. 2. Plan of the city of Valencia showing the location of the archaeological sites (Map: *Nobilis ac Regia Civitas Valentie in Hispania* de Antonio Manceli, 1608).

information based on archaeological samples of Roman, Islamic and Mudejar renderings from archaeological excavations in the city, kept in the Department of Municipal Archaeology of Valencia Town Hall (SIAM) and analysed in the Physical–Chemical and Environmental Analysis Laboratory of the Institute for the Restoration of Heritage of Universitat Politècnica de València. In contrast, the third research phase consisted in systematising all the information compiled from the technical fiches, recording all the data following the same scheme or pattern and providing detailed summary tables. Finally, all the information obtained was used to interpret all the results, analysed for sites individually and globally in order to establish correlations, connections, similarities, differences and contradictions. This helped establish the different material and technical changes in the execution of renderings in the early centuries of the city of Valencia.

3. Continuous Roman, Islamic and Mudejar renderings: historical study, experimental analysis and cataloguing

3.1. Historical study of continuous Roman, Islamic and Mediaeval renderings in Valencia

Man has always used rendering to embellish and protect his dwellings. This centuries-old tradition was already used by early Neolithic cultures of Western Asia, as seen from the remains found in Çatal-Höyük (Turkey) (6600–5650 BC), and the techniques perfected in subsequent centuries.

The Romans were able to build on the experience of earlier cultures, improving and making the most of the qualities and features of renderings, perfecting the use of lime for exterior rendering and plaster for interior decoration. The great secret of the quality of Roman rendering lay in the careful preparation of its components and the meticulous execution and manufacture, and a characteristically careful application of the different mortars which made up the rendering. After the dissolution and fall of the Roman Empire and the different invasions the quality and formal unity of rendering was diminished. In general, although much of the knowledge acquired was lost, rendering was mainly known to have been used for the interiors of Romanesque and Gothic buildings, with no technical progress worth highlighting (Gárate Rojas, 2002). However, there is also some evidence of the existence of exterior renderings in Spanish Romanesque and Gothic constructions, where the stone walls were covered with a thin layer of lime mortar called "*jabelga*" (a mix of lime, sand, mineral pigments and water) with a coloured finish designed to protect the carved stone from the destructive action of the environment (Robador González, 2001).

Thanks to techniques used in Islamic culture, specialising in the execution of plaster rendering, the quality of rendering improved noticeably from the 12th century on, compared with the mediocre renderings of the 9th, 10th and 11th centuries, as part of the knowledge lost was recovered. Islamic rendering came to be highly refined and durable as can be observed in the plasterwork and honeycomb work found in courtyards and interiors of mediaeval Islamic buildings (Moorish Spain). From the 13th century on all constructive knowledge was reflected in Mudejar architecture, which characteristically combined elements of Christian art and Arabic ornamentation, continuing to use plaster decoration in palaces and religious buildings.

Prior to this study, the earliest information about continuous rendering in the city of Valencia dated back to Roman times (2nd c. BC - 8th c. AD) and the sole sources were the different archaeological excavations carried out in its historic centre. Specifically, in the site of the city thermal baths in Plaza de la Almoina interior rendering remains made up of lime mortar, with a reddish tinge due to the addition of ground ceramics, were discovered (Ribera i Lacomba and Jiménez Salvador, 2000). This demonstrates the widespread knowledge of the hydraulic improvements obtained by adding ground fired clay to the lime and sand mix, also known as *coccio pesto*, *pastellones or terrazeto*, one of the early lime-based hydraulic mortars produced using artificial means (Martín Sisí and García y Conesa, 1998). Remains were also found in the excavations of Plaza Cisneros of the remains of Republic renderings in the modest constructions discovered. Based on the remains found it can be stated that in times of the empire and its greatest development, the city of Valencia was aware of the latest technical and decorative advances arriving from Rome (Jiménez Salvador, 2008). Archaeological finds from later centuries show that in Moorish times (8th c.-13th c.) (Mileto and Vegas, 2015) residential constructions had a stone plinth and rammed-earth outer walls, with adobe or rammed-earth partition walls. The rammed earth was lime-crusted or earth rendered with earth and limewashed. Therefore, walls were limewashed and the plinth painted with red ochre. The tradition of rendering

Table 1
Main information about the archaeological excavations.

Archaeological excavation						Rendering	
Name	Excavation	Situation	Year	Description	Date	Period	Samples
RO-01	Unión - Cortes Valencianes	pza S. Lorenzo, 4	1986	Earth bricks, pieces of floor, wall painting	Late Roman, Mid-2nd century	Roman	RO-01.A1 RO-01.A2
RO-02	Sabaters	c/ Zapateros, 9 pza Cisneros, 6	1986	–	Roman	Roman	RO-02.A1
RO-03	Mar	c/Mar	1983	–	Roman	Roman	RO-03.A1 RO-03.A2
RO-04	Roc Chabás IV Campaña	c/ Historiador, c/ Chabás, c/ Unión, c/ Salvador, pza de Crespins	1994	Collapse formed by a clayey soil, with the remains of a wall with decorated rendering	Roman, 3th century–early 4th century?, imperial Roman time	Roman	RO-04.A1 RO-04.A2
RO-05	Sin referencia	–	–	–	Roman	Roman	RO-05.A1 RO-05.A2
IS-01	Mar	c/Mar., 19	1985	–	Islamic, 12th century	Islamic	IS-01.A1
IS-02	Almoyna I campaña	pza Almoyna, 1	1985	–	Islamic, Late 12th century early 13th century	Islamic	IS-02.A1a IS-02.A1b IS-02.A2
IS-03	Almoyna I campaña	pza Almoyna, 1	1985	–	Islamic	Islamic	IS-03.A1
IS-04	Sabaters	c/ Zapateros, 9 pza Cisneros, 6	1986	Yellow sand and gravel	Islamic, 11th century	Islamic	IS-04.A1
MU-01	Palacio Real Valencia	c/ General Elio - Viveros	1986	The sample presents signs of a possible fire	Mudejar	Mudejar	MU-01.A1

Table 2
Results of the optical microscopy analysis (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Sample	Description
RO-01.A1	Material composed of a granulometric distribution of subangular and angular grains in a variety of shades (ochre, grey, white and translucent) and an ochre binder. Presence of coarse saltpetre and a suitable integration with MO-01.A2. The green surface pictorial stratum is very thin.
RO-01.A2	Highly irregular distribution of aggregate grains in grey, ochre, brown and white shades, and an ochre binder. High percentage of aggregate compared to binder. Significant presence of rounded coarse aggregate grains.
RO-02.A1	Irregular distribution of different types of grains in different tonalities (ochre, grey, white and translucent) and an ochre binder. Presence of ceramic fragments dispersed throughout the sample matrix.
RO-03.A1	Apparently very compact material, with irregular distribution of aggregate grains, mostly medium-sized, angular and in very varied shades (browns, beige, greys and whitish) and a whitish binder. Very thin blue surface pictorial stratum.
RO-03.A2	Material composed of irregular distribution of angular and subangular grains in different shades (ochre, grey, white and translucent) and an ochre binder.
RO-04.A1	Presence of predominantly fine aggregate grains in brown, greyish, ochre and whitish shades, as well as light ochre binder. Presence of some saltpetre. On the surface a whitish stratum that is very integrated into the mortar can be observed. Area in contact with RO-04.A2, not clearly outlined, encouraging adherence.
RO-04.A2	Presents an irregular distribution of grains of aggregate in different shades (ochre, grey, white and translucent) and a binder in an ochre shade, slightly darker than that of the exterior mortar. Significant presence of rounded coarse grains of aggregate. Presence of individual fragments of ceramic material.
RO-05.A1	Material made up of a highly irregular distribution of subangular aggregate in mostly ochre and whitish shades, and a very light coloured binder. Reddish surface pictorial layer.
RO-05.A2	Material made up of irregular distribution of different types of grains (rounded, angular and subangular) in different tones (ochre, grey, white and translucent) and a light ochre binder. Presence of very coarse saltpetre.
IS-01.A1	Whitish binder and medium-fine subangular and angular grains of aggregate in ochre, whitish and translucent tones. Apparently compact mortar with multiple cavities that confer it a porous appearance. Very fine reddish surface pictorial stratum.
IS-02.A1a	Presence of superimposed whitish strata (IS-02.A1 s), under which a beige mortar with medium-fine aggregate in a variety of shades (white, ochre, greyish) is detected.
IS-02.A1b	Beige mortar and fine aggregate in mostly beige and whitish tones.
IS-02.A2	In the beige sample it is possible to observe an irregular distribution of medium grains in a variety of tones (pinks, brown, greyish, and whitish).
IS-03.A1	Light brown mortar in an irregular distribution of medium-sized grains of aggregate in whitish and greyish shades. Presence of multiple spherical cavities resulting from bubbles formed during the mortar manufacturing process.
IS-04.A1	Apparently compact material, made up of an irregular distribution of rounded and subangular grains of aggregate in a variety of shades (brown, greyish, whitish) and a whitish binder. Reddish surface pictorial stratum.
MU-01.A1	Material made up of subangular and rounded fine grains of aggregate in whitish and ochre shades, and a beige binder. Presence of small cavities distributed homogeneously in the material.
MU-01.A2	Mortar with highly irregular distribution of medium-large mostly rounded grains and a variety of shades (white, pink, ochre and greyish), and a beige binder. Generally compact appearance with some cavities.

Valencian buildings continued throughout the Middle Ages, and the norm in most cases, with the exception of ashlar masonry, was to apply at least one layer of plaster in the interior in order to improve hygrothermal and sanitary conditions, so that bare stone or brick walls were never left visible, and even those of poor quality were sometimes also treated using bright colours and extremely elaborate

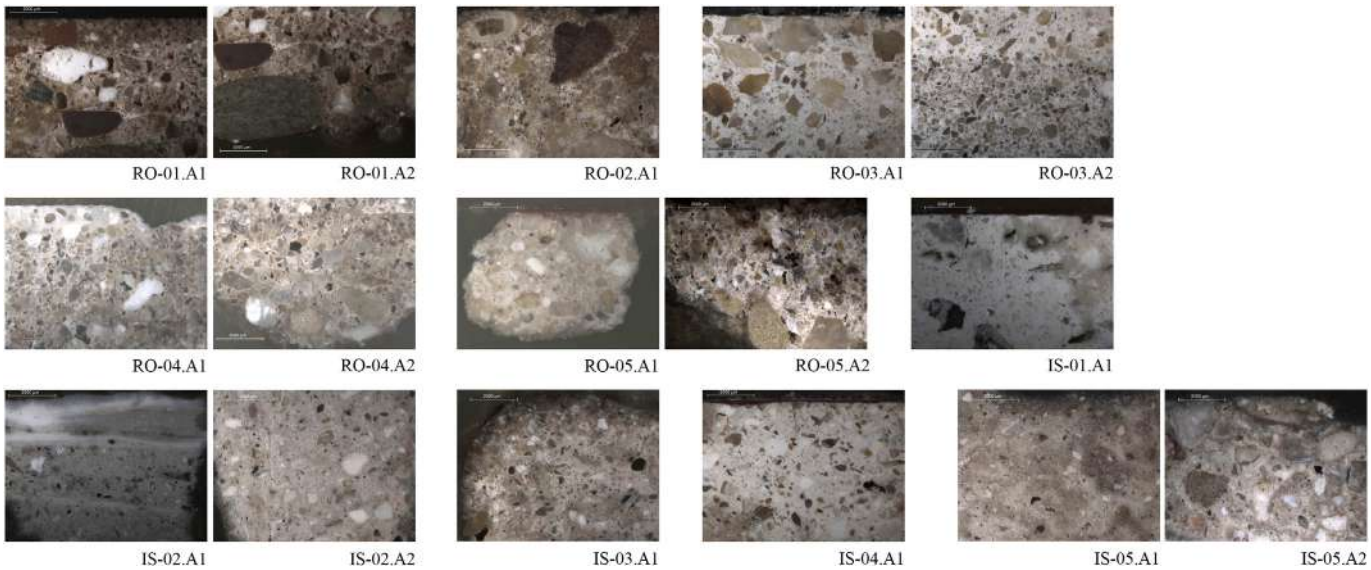

Fig. 3. Cross section of the samples for the optical microscopy study (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Table 3
Results of the granulometric study (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Sample	Description	Dosage (Aggregate:binder)
RO-01.A1	Few particles of size larger than 2.5 mm. Significant proportion of particles retained in sieves larger than 0.8 mm. 40% of sample retained in 0.25 mm intermediate sieve.	3:1
RO-01.A2	30% of particles larger than 2.5 mm. The highest proportion is retained in the coarse and intermediate sieves, mesh size 2.5 and 0.25 mm (30% and 33% respectively)	6:1
RO-02.A1	31% of particles larger than 2.5 mm compared to 24% of particles with a medium sand size. The percentages retained present a characteristic bimodal distribution when two preferred granulometries exist.	3:1
RO-03.A1	A significant proportion of material is retained in the 2.5 mm sieve (16%) indicating an important content of gravel-sized grains in the sample. In contrast, the highest percentage of particles (26%), has medium- sized sand as it is retained in the 0.25 mm sieve	3:1
RO-03.A2	The sample presents a lower proportion of particles larger than 2.5 mm than that of exterior mortar (9%). The highest proportion of the sample is retained in the 0.25 mm intermediate sieve (47% of sample total). The aggregate of the interior mortar is of intermediate granulometry.	2.5:1
RO-04.A1	There is a low percentage of particles larger than 2.5 mm; the highest proportion is retained in the 0.25 mm intermediate sieve (64% of the total). There is a considerable presence of saltpetre that affects the calculation of the dosage. The aggregate grains are medium-fine in size.	3–3.5:1
RO-04.A2	The highest proportion of the sample is retained in the 0.25 mm intermediate sieve (56% of the total of the sample sifted).	2:1
RO-05.A1	The highest proportion of the sample is retained in the 0.25 and 0.125 mm intermediate sieves (37% and 15%, respectively). It is worth noting the high proportion of gravel-sized (4%) and coarse sand (11%) aggregate grains, which correspond to the 2.5 and 1.25 sieves respectively. The granulometric distribution is highly irregular.	3:1
RO-05.A2	In the mortar, 10% of the particles larger than 2.5 mm could be associated to salpetre. The highest sample proportion is retained in the 0.25 mm intermediate sieve (56% of sample total), showing that the grains are mostly medium-sized.	3:1
IS-01.A1	The sample presents 11% of particles larger than 0.25 mm. There are practically no gravel-sized particles and the highest proportion of the sample is retained in the 0.25 mm and 0.125 mm intermediate sieves (43% and 22% respectively), showing that the aggregate is mostly medium-sized.	1:1
IS-02.A1a	The sample has no gravel-sized particles, the highest proportion of the sample is retained in the 0.25 mm and 0.125 mm intermediate sieves (36% and 18% respectively), showing that the aggregate is predominantly medium-fine.	1:1
IS-02.A1b	The sample has no gravel-sized particles, the highest proportion of the sample is retained in the 0.25 mm and 0.125 mm intermediate sieves (32% and 15% of the total of the sifted sample respectively), showing that the aggregate is predominantly medium-fine.	1:1
IS-02.A2	The sample presents a very low proportion of particles larger than 2.5 mm. The highest proportion of the sample is retained in the 0.25 and 0.125 mm intermediate sieves (27% and 26% of the sample total respectively).	1:1 0.25 mm sieve 3:1 0.125 mm sieve
IS-03.A1	Presents a significant proportion (11%) of coarse aggregate grains, although the highest proportion of the sample is retained in the 0.25 and 0.125 mm intermediate sieves (30% and 35% of the total of the sifted sample respectively).	1:1
IS-04.A1	Contains a low percentage of aggregate grains larger than 0.25 mm, while the highest proportion of material is retained in the 0.25 and 0.125 mm sieves (48% and 22% respectively), showing a predominantly medium-fine aggregate.	1:1 0.25 mm sieve 3:1 0.125 mm sieve
MU-01.A1	According to the granulometric distribution, the highest proportion of the sample is retained in the 0.125 mm and 0.25 mm sieve (40% and 30% of the total of the sifted sample respectively), showing that the aggregate is mostly medium-fine.	1:1
MU-01.A2	The sample includes a significant content (12%) of particles larger than 2.5 mm. The highest proportion is retained in the 1.25 mm sieve, meaning the aggregate is coarse, with an important proportion retained in the 0.25 and 0.125 mm intermediate sieves (21% and 17%). The granulometry has bimodal distribution.	3:1

ornamentation (Iborra Bernard, 2015). In addition, decoration in Valencia immediately following the conquest clearly adopted Hispano-Islamic models or early "*mudejarismo*". A prime example of this is the *Casa dels Marbrers*, a sumptuous hall in the east wing of the Palacio el Real, where plasterwork has been restored (Iborra Bernard, 2015).

3.2. The experimental data: results

In order to complete the experimental study some of the remains of renderings from excavations of the city of Valencia, stored in the SIAM, were borrowed. A total of ten archaeological samples dating from Roman, Islamic and Mudejar times were used (Fig. 1). The major drawback of these types of samples is the difficulty in establishing the exact location of the rendering, whether they came from a façade or an interior space, as in most cases these fragments were found alongside other remains covered with earth, rather than forming part of a complete constructive system. In spite of this, municipal archaeologists consider these to be mainly samples from interior renderings.

Simultaneous research was also carried out on the archaeological sites in the city in which the remains of renderings were found in order to compile as much data as possible and date each sample. To do so the archaeological reports from the SIAM for each site were consulted, alongside bibliographical sources, mostly publications on the archaeological excavations carried out in the city (López García, 1990; López García et al., 1994 and Ribera Lacomba, 1998) However, it should be noted that in some specific cases unfortunately the only information that could be obtained on sites was their location (Fig. 2), the date of excavation and the dating of remains as reflected in Table 1.

The experiments and analysis for the characterisation of the ten archaeological rendering samples were carried out by Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó at the Physical–Chemical and Environmental Analysis Laboratory of the Institute for the Restoration of Heritage of Universitat Politècnica de València and consisted of the following studies:

- Morphological. A cross-section examination of the morphological characteristics of the samples (texture, tonality, size of the aggregate) was carried out using Optical Microscopy.

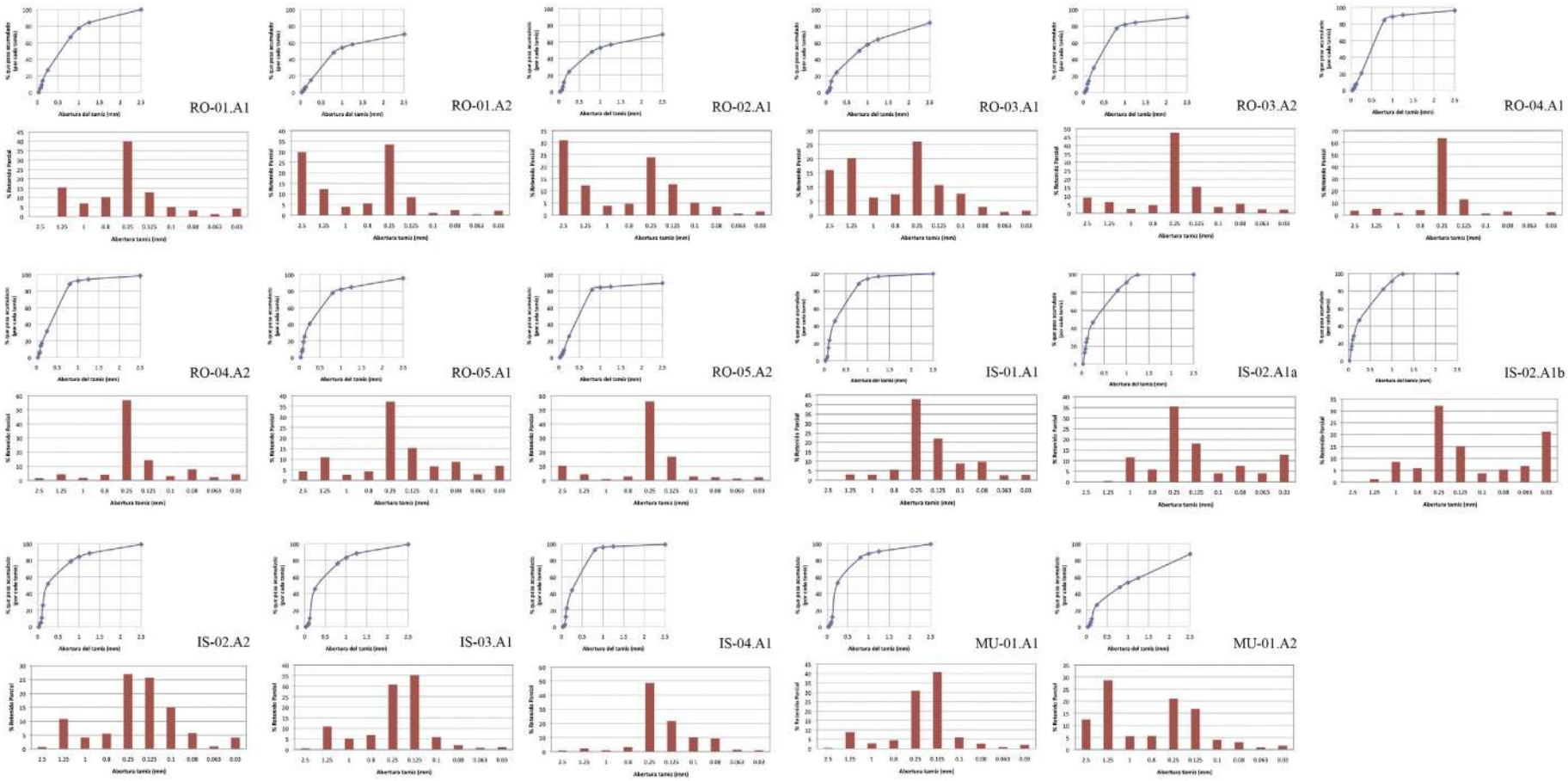

Fig. 4. Graphics of the Granulometric study (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Table 4
Results of the acid treatment study (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner y Dr. María Teresa Doménech Carbó).

	Aggregate		Binder	
Sample	Material/composition	Effervescence	Material/composition	Effervescence
RO-01.A1	46% carbonatic 54% siliceous	+++	60% carbonatic 40% siliceous	+++
RO-01.A2	58% carbonatic 42% siliceous	+++	53% carbonatic 47% siliceous	+++
RO-02.A1	61% carbonatic 39% siliceous	+++	54% carbonatic 46% siliceous	+++
RO-03.A1	95% carbonatic 5% siliceous	+++	91% carbonatic 9% siliceous	+++
RO-03.A2	48% carbonatic 52% siliceous	+++	55% carbonatic 45% siliceous	+++
RO-04.A1	39% carbonatic 61% siliceous	++	54% carbonatic 46% siliceous	+++
RO-04.A2	34% carbonatic 66% siliceous	++	56% carbonatic 44% siliceous	+++
RO-05.A1	84% carbonatic 16% siliceous	+++	84% carbonatic 16% siliceous	+++
RO-05.A2	37% carbonatic 63% siliceous	++	54% carbonatic 46% siliceous	+++
IS-01.A1	70% carbonatic 30% siliceous	++	71% carbonatic 29% siliceous	+++
IS-02.A1a	73% (calcite, soluble gypsum) 27% (insoluble gypsum, siliceous minerals)	1/2+	77% (calcite/dolomite, soluble gypsum) 23% (insoluble gypsum, siliceous minerals)	+
IS-02.A1b	37% (calcite, soluble gypsum) 63% (insoluble gypsum, siliceous minerals)	1/2+	52% (calcite/dolomite, soluble gypsum) 48% (insoluble gypsum, siliceous minerals)	+
IS-02.A2	35% (calcite/dolomite, soluble gypsum) 65% (insoluble gypsum, siliceous minerals)	1/2+	51% (calcite/dolomite, soluble gypsum) 49% (insoluble gypsum, siliceous minerals)	+
IS-03.A1	33% (calcite/dolomite, soluble gypsum) 67% (insoluble gypsum, siliceous minerals)	1/2 +	59% (calcite/dolomite, soluble gypsum) 41% (insoluble gypsum, siliceous minerals)	+
IS-04.A1	73% carbonatic 27% siliceous	+++	84% carbonatic 16% siliceous	+++
MU-01.A1	39% soluble (calcite, soluble gypsum) 61% insoluble (insoluble gypsum, siliceous minerals)	+	62% (calcite, soluble gypsum) 8% (insoluble gypsum, siliceous minerals)	++
MU-01.A2	32% (calcite, soluble gypsum) 68% (insoluble gypsum, siliceous minerals)	+	72% (calcite, soluble gypsum) 28% (insoluble gypsum, siliceous minerals)	++

Table 5
Results of Fourier transform infrared spectroscopy analysis (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Sample	Aggregate	Binder
RO-01.A1	Mixed nature of calcite and siliceous minerals. Presence of sulphates	Calcite, feldspars, traces of quartz and presence of sulphates
RO-01.A2	Mixed nature of calcite and siliceous minerals. Presence of sulphates	Calcite and to a lesser extent siliceous minerals (clay, feldspars and quartz) and sulphates
RO-02.A1	Mixed nature with bands of calcite and siliceous minerals	Calcite and to a lesser extent siliceous minerals (clay minerals, feldspars and traces of quartz)
RO-03.A1	The main component is calcite and secondary are siliceous minerals (feldspars, quartz) and sulphates	Calcite and to a lesser extent siliceous minerals (feldspars and quartz) and sulphates
RO-03.A2	Mixed nature, calcite and siliceous minerals (clay minerals, feldspars and quartz)	Calcite in major proportion of siliceous minerals (clay minerals, feldspars and traces of quartz)
RO-04.A1	Mixed nature with bands of calcite and siliceous minerals (feldspars, clay minerals and quartz)	Calcite and to a lesser extent siliceous minerals (feldspars and traces of quartz) and sulphates
RO-04.A2	Mixed nature with bands of calcite and siliceous minerals (clay minerals, feldspars and quartz)	Calcite and to a lesser extent siliceous minerals (clay minerals, feldspars and quartz) and sulphates
RO-05.A1	Carbonatic nature, calcite and abundance of siliceous minerals (feldspars and quartz) and dolomite	Calcite and to a lesser extent siliceous minerals (feldspars) and sulphates
RO-05.A2	Mixed nature, calcite and siliceous minerals (clay minerals, feldspars and quartz)	Calcite and to a lesser extent siliceous minerals (clay minerals, feldspars and traces of quartz) and sulphates
IS-01.A1	Mixed nature, but more carbonatic (calcite) than siliceous (siliceous minerals: feldspars) and sulphates	Calcite main mineralogical phase and siliceous minerals (clay minerals and quartz)
IS-02.A1a	Gypsum, siliceous minerals in minor proportion and dolomite as minor component	Gypsum and siliceous minerals are the main components and the proportion of dolomite is higher than aggregate
IS-02.A1b	Gypsum and to a lesser extent dolomite, calcite and siliceous minerals	Gypsum and to a lesser extend of calcite (more than in the aggregate) dolomite and siliceous minerals
IS-02.A2	Gypsum crystals and bands of calcite, dolomite, siliceous minerals (feldspars)	Gypsum and to a lesser extend of calcite, dolomite and siliceous minerals (feldspars)
IS-03.A1	Gypsum and, to a lesser extent, calcite, dolomite siliceous minerals (feldspars)	Gypsum and, to a lesser extent, calcite, dolomite and siliceous minerals (feldspar)
IS-04.A1	Calcite and to a lesser extent siliceous minerals (clay minerals, feldspars and quartz) and sulphates	Calcite and to a lesser extent clay minerals, feldspars and traces of quartz. Organic material
MU-01.A1	Gypsum crystals and to a lesser extent calcite and dolomite and siliceous minerals (feldspars)	Gypsum and to lesser extent calcite and siliceous minerals (feldspars)
MU-01.A2	Gypsum, and to a lesser extent calcite, dolomite and siliceous minerals (feldspars)	Mainly gypsum, calcite and siliceous minerals (clay minerals and quartz)

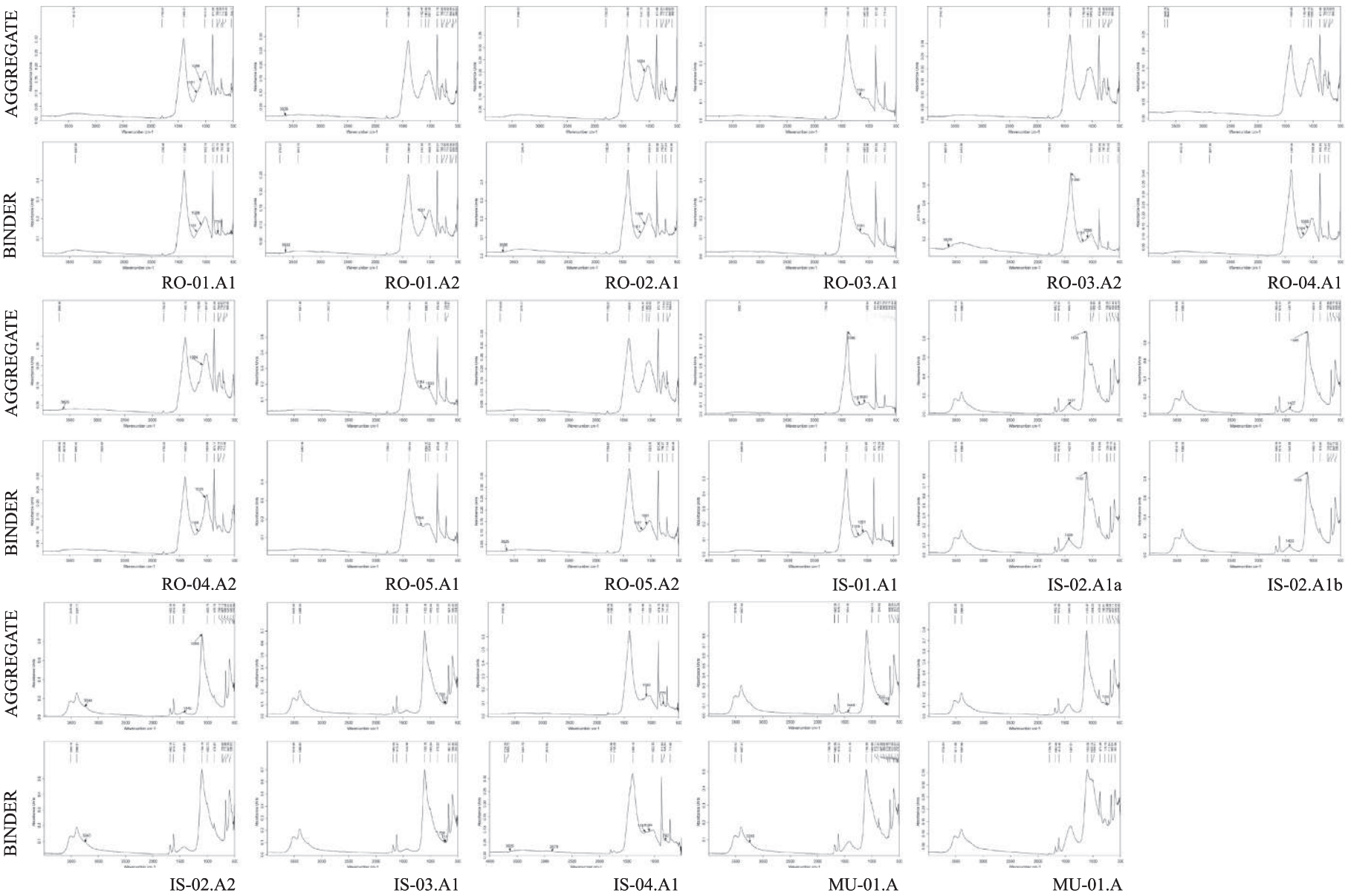

Fig. 5. Spectrometers of the samples analysed (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Table 6
Results of Scanning Electron Microscopy (SEM/EDX) (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Sample	Description
RO-01.A1	Mixed aggregate, composed of calcite (CaCO3), quartz (SiO2) and clay minerals associated with fragments of grog or brick. The major component is calcite (CaCO3), but there are also significant proportions of clay minerals.
RO-01.A2	Mixed aggregate with grains of calcite (CaCO3), quartz (SiO2), feldspars and small proportions of dolomite (CaMg(CO3)2). The binder is primarily made of calcite (CaCO3) with presence of clay minerals. Presence of a very fine stratum of calcite between both sample materials.
RO-02.A1	Mixed aggregate, composed of calcite (CaCO3) and siliceous minerals (quartz SiO2, feldspars and clay minerals associated with fragments of grog or brick). The predominant mineralogical phase of the binder is calcite (CaCO3), but there is also a presence of clay minerals.
RO-03.A1	Calcite (CaCO3) is the main component of the aggregate and binder. Quartz (SiO2) is present in some grains of aggregate while clay minerals are found in the binder. The presence of copper (Cu) associated to a copper pigment (probably azurite) has been identified in the pictorial stratum.
RO-03.A2	Mixed aggregate: calcite (CaCO3) and siliceous minerals (quartz: SiO2 and feldspars mostly). The predominant mineralogical phase of the aggregate is calcite (CaCO3), although small proportions of clay minerals and salts (sulphates and phosphates) are also detected.
RO-04.A1	Mixed aggregate: calcite (CaCO3) and quartz (SiO2) The major component of the binder is calcite (CaCO3) but a small proportion of siliceous minerals is also present. The whitish surface stratum is composed of calcite
RO-04.A2	Mixed aggregate: calcite (CaCO3) and siliceous minerals (mostly quartz:SiO2). The predominant mineralogical phase of the binder is calcite (CaCO3), although there is also a significant presence of clay minerals.
RO-05.A1	Carbonatic aggregate due to the predominant presence of grains of calcite (CaCO3) and the isolated presence of quartz (SiO2). The major component of the binder is calcite (CaCO3), although siliceous minerals and sulphates are also detected. Presence of mercury sulphide (HgS) in the superficial pictorial stratum and calcite (CaCO3) as the inert filler in paint.
RO-05.A2	Mixed aggregate: calcite (CaCO3) and siliceous minerals (quartz: SiO2, feldspars and clay minerals). It is also confirmed that the whitish aggregate is calcite (CaCO3). The major component of the binder is calcite (CaCO3), although significant proportions of clay minerals are also identified.
IS-01.A1	Mixed aggregate: carbonatic and siliceous. Major presence of calcite and clay minerals and sulphates in lower proportion in the binder. Presence of iron in the surface pictorial stratum, associated to the presence of natural earth whose pigment provides the reddish tones.
IS-02.A1s	The surface whitish strata are gypsum (CaSO4.2H2O) and accessory siliceous minerals. Between the most superficial layer and the one immediately below some accumulation of calcite (CaCO3) was detected. A slight accumulation of siliceous minerals, slightly darker and thicker, was also detected between the exterior layers, possibly dust or dirt, as some time elapsed between the application of both layers.
IS-02.A1a and IS-02.A1b	Gypsum mortars (CaSO4.2H2O), with mixed aggregate made up of gypsum crystals, siliceous minerals and calcite (CaCO3), but with a greater concentration of clay minerals and dolomite (CaMg(CO3)2) in the binder for the intermediate layer.
IS-02.A2	Mixed aggregate: gypsum crystals (CaSO4.2H2O), calcite (CaCO3), dolomite (CaMg(CO3)2) and siliceous minerals. Major presence of gypsum in the binder and of smaller proportion of clay minerals and dolomite.
IS-03.A1	Mixed aggregate: gypsum crystals (CaSO4.2H2O), grains of calcite (CaCO3), dolomite (CaMg(CO3)2) and siliceous minerals, as revealed by the occasional analyses carried out. The major component of the binder is gypsum, but small proportions of clay minerals and dolomite are also identified.
IS-04.A1	Mixed aggregate: calcite (CaCO3) and quartz (SiO2) and feldspars. Major presence of calcite (CaCO3) in the binder, showing that it is a lime mortar, although small proportions of siliceous minerals and salts (sulphates and chlorides) are also identified
MU-01.A1	Mixed aggregate: gypsum (CaSO4.2H2O), siliceous minerals (quartz, feldspars and clay minerals), dolomite and calcite. The major component of the binder is gypsum (CaSO4.2H2O), although small proportions of siliceous minerals are also detected.
MU-01.A2	Mixed aggregate: calcite (CaCO3), quartz (SiO3), feldspars, gypsum (CaSO4.2H2O), dolomite (CaMg(CO3)2) and clay minerals. Major presence of gypsum (CaSO4.2H2O) in the binder, but there is also a significant presence of clay minerals, and to a lesser extent, calcite (CaCO3). Presence of foraminifera skeletons, suggesting the use of sand of marine origin in the production of the mortar.

- Physical–chemical. The ratio of all the granulometric fractions presented in the samples were determined through a granulometric study to determine their dosage (ratio aggregate: binder) and to also establish the insoluble residue using acid treatment.
- Chemical–mineralogical. The mineral phases of aggregates and binders of mortars were defined, using analysis with Fourier Transform Infrared Spectroscopy (FT-IR) and Scanning Electron Microscopy (SEM/EDX).

Therefore, the archaeological samples were subjected to the following tests:

- Visual description. Without any instrumental aid the samples were visually classified by directly observing their appearance, thickness, number of layers, surface paint, etc.
- Optical microscopy. With a Leica S8AP0, ×10-×80 microscope with an integrated digital camera and transmitted light (Table 2) (Fig. 3).
- Granulometric study. The granulometric study and separation by size of the different fractions that compose a sample was obtained by pulverising it and using a series of standard sieves (Table 3) (Fig. 4).
- Acid treatment. The aim of this analysis is to identify the insoluble residue of the aggregate and binder following its treatment with hydrochloric acid. The insoluble residue remaining after the reaction corresponds to the non carbon material present in the sample, generally siliceous minerals (quartz, feldspar, clay minerals, etc.). In mortars, after acid immersion the remains found on the filter paper are generally the fraction of clean aggregate in the thicker fractions. In contrast, the insoluble residue of fine fractions is a mix of aggregate and binder with minuscule particles and powder (Table 4).
- Fourier Transform Infrared Spectroscopy (FT-IR). For the specific analysis of samples an Equo Vertex 70, Bruker Optics spectrometer with attenuated total reflectance (ATR) and temperature-stabilised coated FR-DTGS detector was used. Number of scans accumulated: 32, resolution 4 cm-1 (Table 5) (Fig. 5).
- Scanning Electron Microscopy (SEM/EDX): This study used a JEOL JSM 6300 microscope with a Link-Oxford-Isis microanalysis system, with a filament current of 20 kV, a current strength of 2.10^{-9} A and a working distance of 15 mm (Table 6) (Fig. 6).

And the main results are summarized in Table 7.

3.3. Systematisation of data: an open catalogue

The main aim of the systematisation of all the data collected was to facilitate its subsequent interpretation both overall and for individual samples in order to establish relationships, links, differences, etc. between the actual historic reconstruction and the theory reflected in treatises and publications. For this, specific fiches were produced to develop information in greater or lesser detail, depending on the

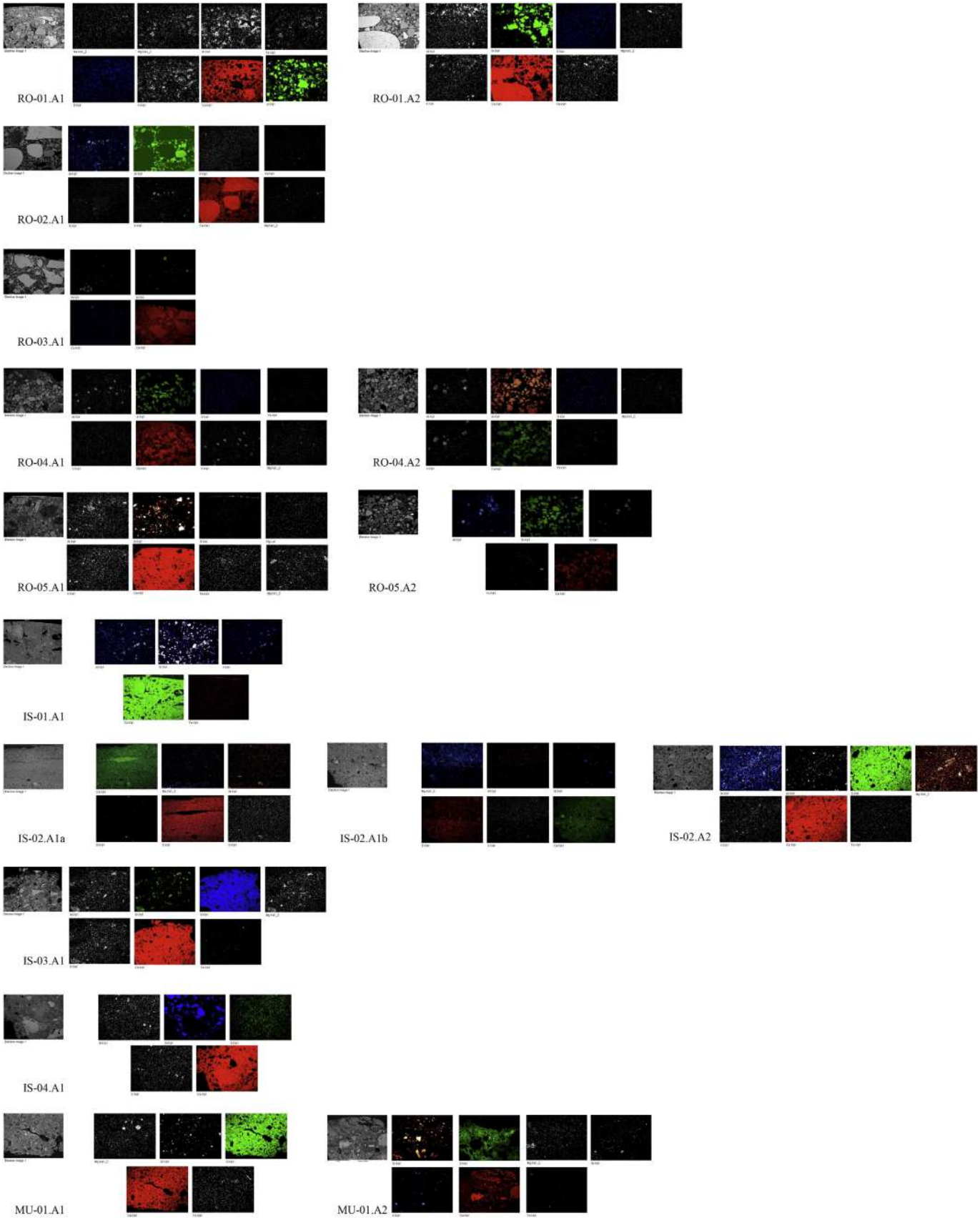

Fig. 6. Images of the Scanning Electron Microscopy study (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

Table 7
Results of the experimental data of the archaeological samples (authors: Dr. Laura Osete Cortina, Dr. Stephan Kröner and Dr. María Teresa Doménech Carbó).

	Composition			Acid attack	
Sample	Aggregate	Binder	dosage (A:B)	Aggregate	Binder
RO-01.A1	Mixed nature (calcite, siliceous minerals) Grains shape: subangular and angular Medium size	Calcite and clay minerals	3:1	46% carbonatic 54% siliceous	60% carbonatic 40% siliceous
RO-01.A2	Mixed nature (calcite, siliceous minerals, dolomite) Grains shape: rounded Very large size	Calcite and clay minerals	6:1	58% carbonatic 42% siliceous	53% carbonatic 47% siliceous
RO-02.A1	Mixed nature (calcite, siliceous minerals) Grains shape: subangular and rounded Very large size	Calcite, clay minerals	3:1	61% carbonatic 39% siliceous	54% carbonatic 46% siliceous
RO-03.A1	Mainly carbonatic nature (calcite) Grains shape: angular Medium size	Calcite (majority), clay minerals (minority)	3:1	95% carbonatic 5% siliceous	91% carbonatic 9% siliceous
RO-03.A2	Mixed nature (calcite, siliceous minerals) Grains shape: subangular and angular Medium size	Calcite, clay minerals sulphates, phosphates (salts)	2.5:1	48% carbonatic 52% siliceous	55% carbonatic 45% siliceous
RO-04.A1	Mixed nature (calcite, siliceous minerals) Grains shape: subangular and angular Medium-small size	Calcite and siliceous minerals	3–3.5:1	39% carbonatic 61% siliceous	54% carbonatic 46% siliceous
RO-04.A2	Mixed nature (calcite, siliceous minerals) Grains shape: subangular and rounded Medium-large size	Calcite and clay minerals	2:1	34% carbonatic 66% siliceous	56% carbonatic 44% siliceous
RO-05.A1	Mainly carbonatic nature (calcite) Grains shape: subangular Medium size	Calcite (majority), siliceous minerals (minority), sulphates (salts)	1:1 3:1 (sieve 0.125 mm)	84% carbonatic 16% siliceous	84% carbonatic 16% siliceous
RO-05.A2	Mixed nature (calcite, siliceous minerals) Grains shape: rounded, subangular and angular Medium size	Calcite and clay minerals	3:1	37% carbonatic 63% siliceous	54% carbonatic 46% siliceous
IS-01.A1	Mainly carbonatic nature Grains shape: subangular and angular Medium-small size	Calcite (majority), clay minerals (minority), sulphates (salts)	1:1	70% carbonatic 30% siliceous	71% carbonatic 29% siliceous
IS-02.A1a	Mixed nature (gypsum, calcite, siliceous minerals) Grains shape: subangular and rounded Medium-small size	Gypsum (majority), clay minerals, dolomite	1:1	73% (calcite, soluble gypsum) 27% (insoluble gypsum, siliceous minerals)	77% (calcite/dolomite, soluble gypsum) 23% (insoluble gypsum, siliceous minerals)
IS-02.A1b	Mixed nature (gypsum, calcite, siliceous minerals) Grains shape: subangular and rounded Small size	Gypsum (majority), clay minerals, dolomite (minority)	1:1	37% (calcite, soluble gypsum) 63% (insoluble gypsum, siliceous minerals)	52% (calcite/dolomite, soluble gypsum) 48% (insoluble gypsum, siliceous minerals)
IS-02.A2	Mixed nature (gypsum, calcite, dolomite, siliceous minerals) Grains shape: subangular and rounded Medium size	Gypsum (majority), clay minerals, dolomite (minority)	1:1 (sieve 0.25 mm) 3:1 (sieve 0.125 mm)	35% (calcite/dolomite, soluble gypsum) 65% (insoluble gypsum, siliceous minerals)	51% (calcite/dolomite, soluble gypsum) 49% (insoluble gypsum, siliceous minerals)
IS-03.A1	Mixed nature (gypsum, calcite, dolomite, siliceous minerals) Grains shape: subangular and rounded Medium size	Gypsum (majority), clay minerals, dolomite (minority)	1:1	33% (calcite/dolomite, soluble gypsum) 67% (insoluble gypsum, siliceous minerals)	59% (calcite/dolomite, soluble gypsum) 41% (insoluble gypsum, siliceous minerals)
IS-04.A1	Mixed nature (calcite, siliceous minerals) Grains shape: subangular and rounded Medium size	Calcite (majority), siliceous minerals, sulphates (salts)	1:1 (sieve 0.25 mm) 3:1 (sieve 0.125 mm)	73% carbonatic 27% siliceous	84% carbonatic 16% siliceous
MU-01.A1	Mixed nature (gypsum, siliceous minerals, calcite, dolomite) Grains shape: subangular and rounded Small size	Gypsum, siliceous minerals, traces calcite	1:1	39% soluble (calcite, soluble gypsum) 61% insoluble (insoluble gypsum, siliceous minerals)	62% (calcite, soluble gypsum) 8% (insoluble gypsum, siliceous minerals)
MU-01.A2	Mixed nature (gypsum, calcite, dolomite, siliceous minerals) Grains shape: rounded	Gypsum (majority), clay minerals, calcite (minority)	3:1	32% (calcite, soluble gypsum) 68%	72% (calcite, soluble gypsum) 28%

Table 7 (*continued*)

Sample	Composition		dosage (A:B)	Acid attack	
	Aggregate	Binder		Aggregate	Binder
				(insoluble gypsum, siliceous minerals)	(insoluble gypsum, siliceous minerals)
	Medium-large size				

documentation obtained and the analyses carried out. However, these all follow the same basic organisation, with specific major points reflecting the most salient aspects of the site and including all the results of the scientific analyses (Fig. 7). Thus, the information included is as follows:

Information on archaeological site.

Identification information: excavation (name), location (current address), date (year), technical team (archaeologists), EU (execution unit), description (excavation elements), interpretation (according to SIAM archaeological report), date (archaeological remains).

Graphic information: plan of the city of Valencia, photographs and images of the site taken from publications consulted.

General information: brief information about the site, including the bibliography consulted.

Sample information.

Visual description.

Morphological study: Optical microscopy.

Granulometric study and insoluble residue after acid treatment: Granulometric analysis, Dosage: aggregate /binder, Acid treatment.

Chemical–mineralogical: Fourier Transform Infrared Spectroscopy (FT-IR) and Scanning Electron Microscopy (SEM/EDX).

4. Discussion

Organising all the information and simultaneously analysing the historical data and scientific results led to the definition of the main technical, typological, and above all, material features of the archaeological samples analysed. Thus, it was possible to determine the number of layers making up each rendering, thickness, the dosage of the mortar (ratio of aggregate and binder), surface finish and binder or main material of the rendering (Table 8).

When analysing the ten samples and seventeen different mortars jointly using the material of archaeological renderings and the historic period they were executed in as reference, it is worth noting that all the Roman samples are lime renderings. This confirms the almost exclusive use of this material for rendering Roman constructions, also reflected in historical documents. Another possible conclusion is that if this material was chosen for rendering interior spaces it was almost definitely used to protect and cover building façades. In contrast, despite the widespread belief that gypsum was the main material used in Islamic construction culture, only 50% of the samples analysed for this period are in this material. It can therefore be stated that in the city of Valencia the tradition of lime renderings continued during the Moorish occupation, perhaps also due to the geological features of the city's surroundings with their nearby limestone sites and quarries, such as Godella or Moncada. And, the only sample of Mudejar rendering is completely made up of gypsum, thought by archaeologists to have probably been part of an example of plasterwork from a courtyard of what was the *Palacio del Real de Valencia* (the court from the 11th to the beginning of the 19th century), and which showed signs of having been in a fire, perhaps a direct consequence of the destruction of the building in 1810. Although this rendering might have been exposed to inclement weather it was still made of gypsum, just like most of the continuous renderings of façades of residential historic buildings in Valencia. Moreover, there is a significant presence of clay minerals, specifically impurities of K, Na, Si and Mg, in the composition of the binder in almost all of the samples analysed, both lime and gypsum. In the case of gypsum rendering this may be due to impurities characteristic of raw gypsum, given the low calcination temperature for the gypsum (Vegas et al., 2010). However, in the lime samples it is more probable that these impurities are found in the aggregate or in lime with some marble content. In addition, the clay minerals found in the aggregate are the result of the addition of brick or firesand (chamotte) to improve the hydraulicity of the mix. As regards the construction technique, it is firstly worth noting the presence of high proportions of aggregate in both gypsum and lime rendering samples, a construction technique not to be found in surviving historic external renderings in Valencia, which according to the research carried out gypsum renderings have higher proportions of binder than aggregate. In contrast, the usual proportions are maintained in the case of lime renderings, which do require the addition of an inert material to support shrinkage and prevent the appearance of surface fissures. Secondly, it should be noted that most of the renderings analysed have a smooth finish, with pictorial surfaces as in the case of all the Roman samples. However, in the case of the Islamic samples colour is only present or at least conserved in the samples of lime mortar renderings, since plaster renderings, such as the only example of Mudejar rendering analysed, do not show signs of colour. A direct connection can be established between the material of the rendering and its subsequent finish. It can also be observed how the total thicknesses are high even in the case of single-layer samples such as RO-02.A, IS-01.A and IS-04.A. This is striking if you take into account that these are mainly interior renderings. Nevertheless, it should also be taken into consideration that the total or partial thickness of each rendering can vary considerably, even on different points of the same wall, given that their main purpose is to even off the surface to ensure it is completely flat and conceal any possible imperfections. In addition, the presence of different layers forming most of the rendering analysed reaffirm the recommendations made by Vitruvius in his treatise detailing the execution of at least one layer of mix followed by another also composed of several layers to improve features and resistance. The dosages of the different layers are either very similar or very different. In the case of the latter interior layers generally contain more aggregate than exterior ones. In short, this follows the more efficient practice of using mortars with less aggregate and more binder in the final layers of renderings, since these are more pliable and workable, albeit less stable. In contrast, in the initial layers mortars contain more aggregate and are subsequently more stable to resist shrinkage, both in lime and gypsum renderings, although the latter do not necessarily require this. Instead of shrinking like lime, gypsum expands when it hardens which means it may have been used either due to construction parallels with lime or to reduce the amount of binder in the mix, bringing down the total cost of the rendering.

5. Conclusions

The study of renderings from archaeological excavations in the city of Valencia provided knowledge of their construction materials and techniques in greater detail than that provided by bibliographical sources up until now. The most significant aspect is the widespread use of lime, even in Moorish times, to render the interiors of buildings, confirming the likelihood that lime was also the material used to render the exterior of building façades during the period analysed. This material feature differs considerably from the characteristic façade renderings of residential constructions from the 18th, 19th and early 20th centuries in the historic centre of Valencia, where gypsum definitely predominates, especially in the 19th century.

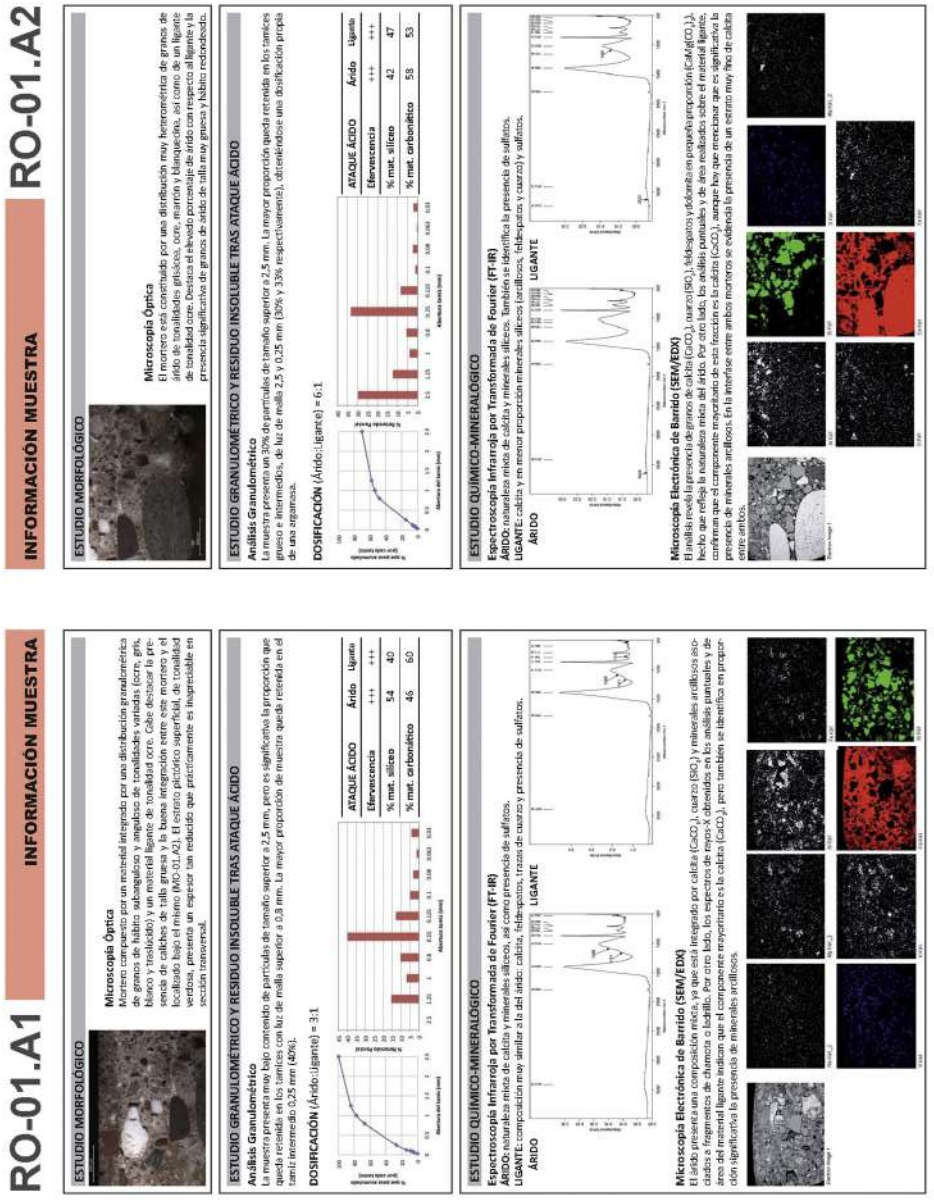

Fig. 7. Example of fiche containing all the sample information.

Table 8
Main technical, typological, and material features of the archaeological samples analysed.

Archaeological excavation		Rendering					
Name	Period	Samples	Technique			Tipology	
			Layer	Thickness (mm)	Dosage (Aggregate:binder)	Finish	Material
RO-01	ROMAN (Mid-second century)	**A** [A1, A2]	2	20	3:1 6:1	Smooth painted	Lime
RO-02	ROMAN	**A** [A1]	1	15	3:1	Smooth painted	Lime
RO-03	ROMAN	**A** [A1, A2]	2	18 - 25	3:1 2.5:1	Smooth painted	Lime
RO-04	ROMAN (3th century–early 4th century)	**A** [A1, A2]	2	12	3–3.5:1 2:1	Smooth painted	Lime
RO-05	ROMAN	**A** [A1, A2]	2	20 - 30	1:1 3:1 (sieve 0.125 mm) 3:1	Smooth painted	Lime
IS-01	ISLAMIC 12th century	**A** [A1]	1	15	1:1	Smooth painted	Lime
IS-02	ISLAMIC (Late 12th century - early 13th century)	**A** [A1(a y b), A2]	3	30	1:1 1:1 (sieve 0.25 mm) 3:1 (sieve 0.125 mm)	Smooth	Gypsum
IS-03	ISLAMIC	**A** [A1]	1	10	1:1	Smooth	Gypsum
IS-04	ISLAMIC 11th century	**A** [A1]	1	12 - 20	1:1 (sieve 0.25 mm) 3:1(sieve 0.125 mm)	Smooth painted	Lime
MU-01	MUDEJAR	**A** [A1, A2]	2	variable	1:1 3:1	Smooth, plasterwork	Gypsum

Finally, other aspects worth noting and closely linked with the use of lime mortars for renderings are the considerable thicknesses of the samples analysed, which are from interior renderings, as well as the high proportion of aggregate in the mixes and the presence of pictorial surfaces, in both the Roman and Islamic samples. In contrast, gypsum is only featured in a few Islamic renderings and the sole Mudejar one, which do not have pictorial finishes.

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