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ORIGINAL ARTICLE

Building Granite Characterisation, Construction Phases, Mason's Marks and Glyptography of Nossa Senhora de Guadalupe Church, Mouçós e Lamares, Galicia-North Portugal Euroregion

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Abstract
The Romanesque church of Nossa Senhora de Guadalupe of Mouçós e Lamares is located in Vila Real (North of Portugal). The exterior part of its nave is preserved almost unaltered. Most of the granite ashlars and corbels that make up this church have a mason's mark in the centre of their faces. The building granites (Sanguinhedo and Vale das Gatas) have been identified and characterised petrographically and petrophysically. The mason's marks have been as well identified; all the ashlars with visible mason's marks have been mapped, and a glyptographic study has been carried out. In addition, the surface roughness of ashlars was measured. All these analyses have made it possible to locate the main historical quarry, to calculate the number of stonemasons who worked in the construction of the church, and to determine its construction phases. There are eight main types of mason's marks on the nave façades. The quarrymen extracted the main building granite (Sanguinhedo granite) from the same quarry, or from nearby quarries. Although the most experienced stonemason has been identified, most stonemasons worked as a team during all construction phases of the church. Techniques such as petrography, ultrasonic P wave velocity, colourimetry, roughness and the determination of hydric properties will guarantee the quality and durability of the heritage stone for restorations. In addition, the glyptographic analysis revealed important historical and ethnographic findings that will be very useful for the appreciation of the monument. Therefore, the knowledge of built heritage, such as mason's marks contribute to the conservation of historical quarries and traditions, as well as help understand the close cultural association societies have had with heritage stones. In this way, the scientific corpus of historical-cultural heritage can face for the development of tourism in Galicia-North Portugal Euroregion in a long-lasting sustainable way.

Keywords Romanesque and Gothic architecture · Petrography · Granite · Ashlars · Corbels

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Introduction

The building stones have been marked with signs, texts and graphics from prehistoric times to the present day. These signs were mainly carved for votive purposes, to date, to sign and to reflect historical events. They go back thousands of years (Gibson and Taylor 1994; Hammond 2000; Devolder 2018) and they can be seen in the Main Theatre at Petra (9 BC–40 AD). Glyptography is the discipline dedicated to the study of signs carved on hard materials, mainly on heritage stones, and among which the mason's marks stand out (Orabi 2020). Mason's marks are symbols: geometric signs, letters or monograms, carved by stonemasons on dressed stone to get the payment for the work done, or to indicate the correct position of the ashlar. In Europe, one can mainly find mason's marks from the medieval ages (Viollet-Le-Duc 1854; Silva 1868;

Sousa 1929; Frühwirth 2018), mainly in churches like the Royal Collegiate Basilica of San Isidoro de León (Spain, eleventh century); Roche Abbey (England, twelfth century) and Cathedral of Our Lady of Chartres (France, thirteenth century), among many others (Bozal Gonzalez 2013).

The economic, social, political and religious crisis of Europe in the High Middle Ages caused changes in the building patterns that preceded this period (Freire-Lista 2021). Stone constructions reappeared in the Lombard Romanesque, which developed in northern Italy during the tenth and eleventh centuries and spread to the rest of Europe. The stone constructions, characteristic of the Romanesque, were used to promote the monastic orders. The hired stonemasons and master masons knew the quarries and the quality of the stones, mastered the art of sculpture, construction methods and symbolic Romanesque architecture. The mason's workshops or lodges began to acquire certain privileges from the tenth and eleventh centuries (Knoop and Jones 1933; Martínez Prades 1998, 2013). It is from this time until the fourteenth century when mason's marks proliferated.

The art historian and archaeologist Adolphe Napoléon Didron (1806–1867), the writer Xavier Barbier de Montault (1830–1901) and the architect, archaeologist and writer Eugène Viollet-le-Duc (1854) were among the first French authors to analyse mason's marks. Research began to be undertaken, published especially on the pages of the Annales Archéologiques, founded in 1844. The priest and archaeologist Charles-Auguste Auber (1804–1892) wrote about medieval lapidary signs in 1869 (L'Abbé Auber (1869)), Barbier de Montault provided references between 1848 and 1861 in an article published in 1884 (Reveyron 2003). Twenty years later, M. Adrien Blanchet (1866–1957) published a bibliography on mason's marks, in which he presented eighteen ancient glyptographic references and forty medieval ones, published between the years 1856 and 1904 (Reveyron 2003; Esquieu et al. 2007). From the 1880s on, many works about mason's marks appeared in the Congrès Archéologique of France. Most of the studies, apart from the field reports, focused on "reading" the marks. It was typical of researchers to seek the "signified" (who or what the mark can represent) but judged in relation to present-day practices to ignore its value as "signifier" (what the sign is in a strictly material sense, its shape, type of engraving etc.). This focus persisted to the end of the nineteenth century and beyond. In 1883, Franz von Rziha (1831–1997), an Austrian engineer, published a work entitled "Studien über Steinmetz-Zeichen" (Ržiha 1883), in which he proposed that fourteen basic patterns ("keys", "Schlüsseln") underlay his repertory of 1163 Germanic mason's marks: these, he posited, would have permitted the initiated to identify the lodge from which a given stone cutter had issued.

There are several types of mason's marks:

i) Placement marks, signs of rigging made by the stonemasons for the correct placement of the ashlars. These are the simplest marks, which were made in corners or other specific points of the ashlar (Alexander 2007).
ii) Assembly marks that enabled builders to join sectional masonry without written instruction. They usually consist of a Roman numeric sequence, and are often cut across the joint faces of adjacent ashlars (Bozal Gonzalez 2013).
iii) Identity marks, personal marks of each stonemason, referring to their name (initial or monogram), their beliefs or devotions (a symbolic or allegorical object), their present or past social status (a tool of their profession or a sign of slavery), to the time in which he carved the work (for example, an astrological sign).
iv) Marks made by each stonemason as a signature to identify the ashlars made and to facilitate the collection of the work carried out required medieval piecework system, without a contract or salary. The first ones to publish this theory were Didron and Viollet-le-Duc 1845 and 1854 respectively. They considered that mason's marks are lapidary signs belonging to the category of personal signatures of stonemasons and master builder.
v) The marks that we have considered "signatures" can be symbolised either by the initial of the name of the author stonemason (the most common), by some personal or family insignia, or by symbolic allusions to elements with which the author felt identified, whether they were ideological, professional, religious etc. On occasions, stones have even been found signed with the full name of the master builder, either alone, or accompanied by the expression "me fecit" (He made me).
vi) Over the last centuries, several of studies on architecture, archaeology and/or history have contributed significantly to the understanding of medieval mason's marks. Nevertheless, the sheer number of these studies has overlooked the relationships between stonemasons, historical quarries and mason's marks.

The examination of the mason's marks, together with the petrology of the ashlars and the reading of the masonry is an essential link to understand their relative temporal sequence (Martínez Martínez et al. 2012; Münchmeyer 2013; De Llave and Escobar Requena 2018, Freire-Lista et al. 2022a, b). By analysing the mason's marks and the surface roughness of the ashlars, it is possible to find out how many stonemasons worked on a certain work, to determine the construction phases, to calculate how much each stonemason worked, to deduce the financial solvency of the sponsor, and even to track jobs from the stonemasons throughout a region (Sánchez and Tabar 2019).

Having in mind such references, the aims of this study are to characterise the building granites of Nossa Senhora de Guadalupe Church of Mouçós, Vila Real, North of Portugal (Fig. 1), to locate its historical quarries, and to determine the Church's construction phases and the number of stonemasons who worked at its construction.

Natural stones are essential building materials, as they are used as building stones and their use has been recently the object of detail studies (Přikryl 2017; Přikryl et al. 2017; Czinder and Török 2020; Damas Mollá et al. 2021). In the frame of this new interest, the concept of Heritage stone (Cooper 2010; Cooper et al. 2013a, b; Kaur et al. 2020) refers to stones that have a special relevance in human culture. For example, the porphyries from Sweden (Wikström et al. 2015); "Petit granit" and Lede stone from Belgium (Pereira et al. 2015; De Kock et al. 2015); slates from the Iberian peninsula (Cardenes et al. 2015); granites such as Piedra Berroqueña, of Madrid (Spain) (Freire-Lista et al. 2015a, b; Freire-Lista and Fort 2016, 2019a, b) and Rosa Beta granite from Italy (Careddu and Grillo 2015); Larvikites from Norway (Heldal et al. 2015); gneisses such as Facoidal gneiss from Brazil (Castro et al. 2021); marbles, such as the one from Carrara in Italy (Primavori 2015; Murru et al. 2018), the white marbles of Brasília (Frascá et al. 2020), Estremoz marbles from Portugal (Lopes and Martins 2015) and Macael marble from Spain (Navarro et al. 2019); and limestones such Lioz limestone from Portugal (Silva 2019), Bath and Purbeck limestones from England (Marker 2015); Villamayor sandstone from Salamanca (NW of Spain) (García-Talegón et al. 2015), and Sydney sandstone from Australia (Cooper et al. 2015). These stones have been widely used and with them, important buildings have been built that have marked the history of humankind (Siegesmund et al. 2014).

Granite is the most used stone in Galicia-North of Portugal for historical constructions, especially in churches (Barroso and Oliveira 2020; Campos et al. 2021a, b). The recovery of traditional stones involves the study of their historical quarries and their characterisation with petrographic and petrophysical techniques, which allow scientists to establish the degree of decay and durability of building stones (Fort et al. 2013; Forestieri et al. 2017; Zalooli et al. 2020). That is, petrographic and petrophysical properties of stones are an indicator of decay degree and durability (Khanlari et al. 2019; Tomás et al. 2021).

Relevant Stone Elements of the Church

Nossa Senhora de Guadalupe Church of Mouçós e Lamares (Vila Real, North of Portugal) (41° 19′12.3 ″N 7° 42′54.6″ W) is a rural building and stands free on a promontory at the end of a traditional path delimited by granite walls. This elevation creates an esplanade from where a panoramic view of the surrounding mountains can be seen. The area has been populated since prehistoric times and many Celtic vestiges exist.

The Church is made up of three volumes (Fig. 2): a single nave and a lower rectangular apse, both with wooden gabled roof. The sacristy is attached to the NW

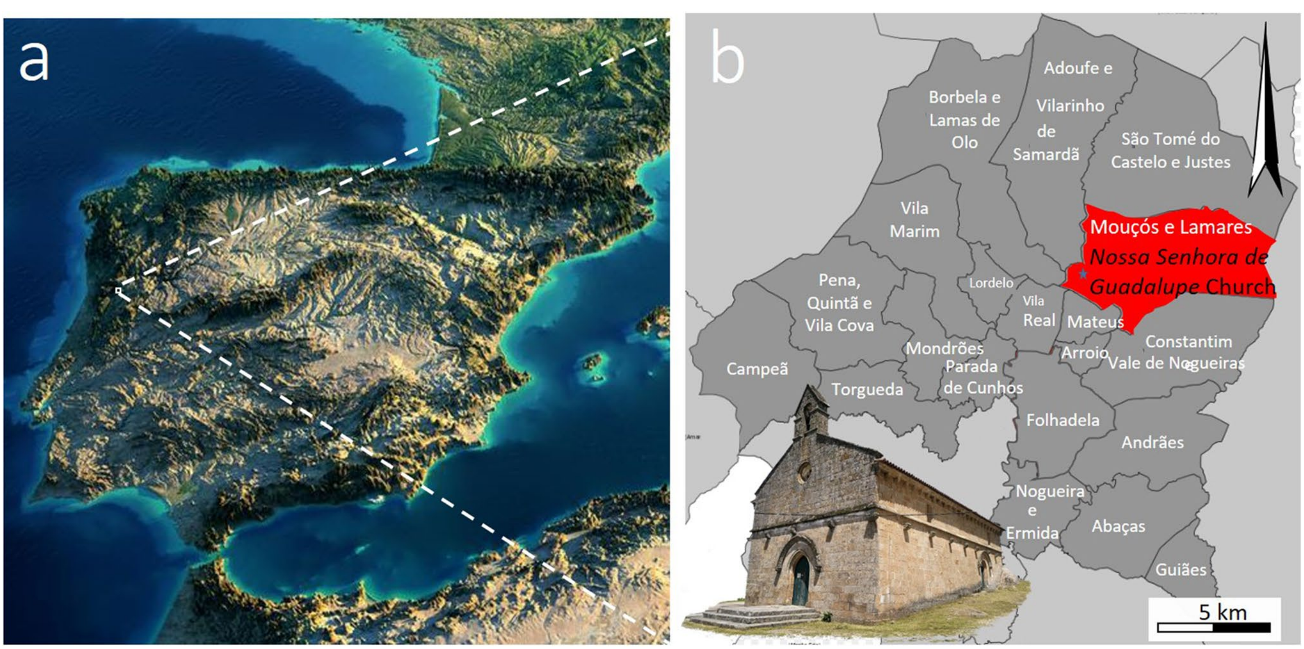


Fig. 1 **A** Map of the Iberian Peninsula indicating the location of the study area. **b** Location map of the Parishes of Vila Real municipality (North of Portugal) with the Nossa Senhora de Guadalupe Church. Mouçós e Lamares is marked in red

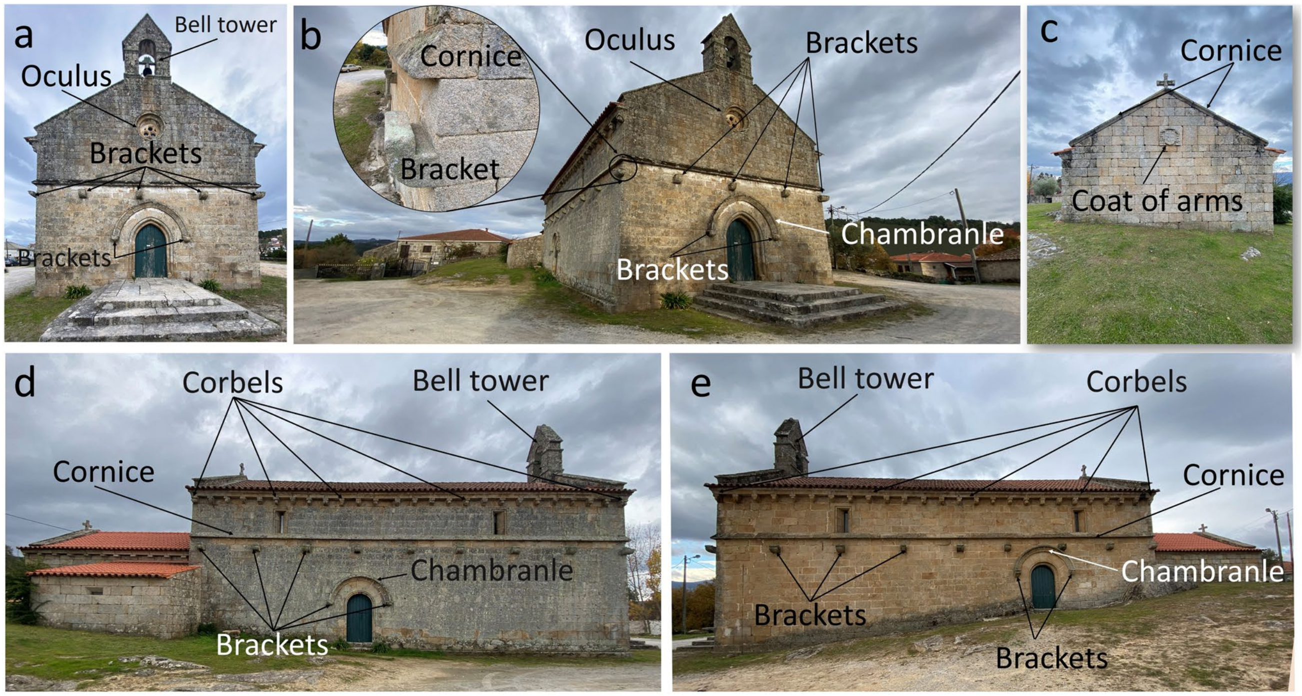


Fig. 2 Nossa Senhora de Guadalupe Church. **a** SW façade (main façade). **b** General view of the Church. The brackets that supported the wooden beams and the cornice above are seen in detail. **c** NE apse façade (rear façade). **d** NW façade. **e** SE façade. Note the difference in biological colonisation between the NW and SE façades. Apparently, the SE façade does not show biological colonisation

façade of the apse and has a single-pitched wooden roof. The church nave has double-leaf walls and it is built with dressed granite ashlars. Most of them have a mason's mark in their center.

To compensate for the existing slope (slightly inclined to the NW), the NW façade has one more row of granite ashlars. A horizontal cornice divides the façades of the nave into two sections: the lower one is made up of 17 and 16 courses of granite ashlars (including the course corresponding to the division cornice); the second one has six courses of granite (including the row of corbels and upper cornice); the pediment has 10 courses of granite ashlars, and the bell tower has another 10 courses of granite ashlars (Fig. 2).

The main façade is oriented to the SW and has a pointed arch door composed of 7 voussoirs on a rectangular platform with three steps. The door has two archivolts and is highlighted by a door frame, chambranle, made up of nine wedge-shaped ashlars and two archivolts. Each ashlar that forms the chambranle is decorated with a sinuous branch from which leaves and tetrapetal flowers sprout (Fig. 3a (1–9)). Both basal extremes of the chambranle have a bracket decorated with a female head, the one on the left showing her hair (Fig. 3a (10–12)). There are five equidistant brackets supporting a formerly existing wooden ceiling in the course of granite immediately above the chambranle (fifteenth granite ashlar row). Above it, there is a cornice to protect the wooden beams that constituted the previously existing ceiling.

A moulded oculus (9 wedge-shaped ashlars) is present on the upper level of the main façade. This oculus has inside a circular granite piece where three clover-shaped circles open. The southern façade of the nave also shows signs of having been modified and enlarged. Ashlars and granite masonry filling arches are observed in this wall. It currently has a door and two rectangular windows (Fig. 4) part by a gabled bell tower with a semi-circular arch span and a bell. The bell tower is also topped with a cornice (Fig. 2a, b).

The SE façade of the nave has a semi-circular arch door made up of 7 voussoirs. Above, there is a chambranle of 6 wedge-shaped ashlars, composed of two archivolts and a central space in which each ashlar has a different vegetal decoration (leaves and flowers). Each end of the chambranle has a bracket, one decorated with a lamb with a dove, and the other one with the face of a bearded male (Fig. 3b (7)). Above the chambranle, there are eight equidistant brackets along the entire front of the façade supporting a formerly existing wooden roof and, above it, a protective cornice for the beams of the said roof. On the brackets and on the cornice, there are mason's marks, as the ashlars. On the upper level, there are two rectangular flared windows with an archivolt on the outer perimeter, and 26 sculpted corbels supporting the upper cornice on which the roof tiles lie (Fig. 2e and 4).

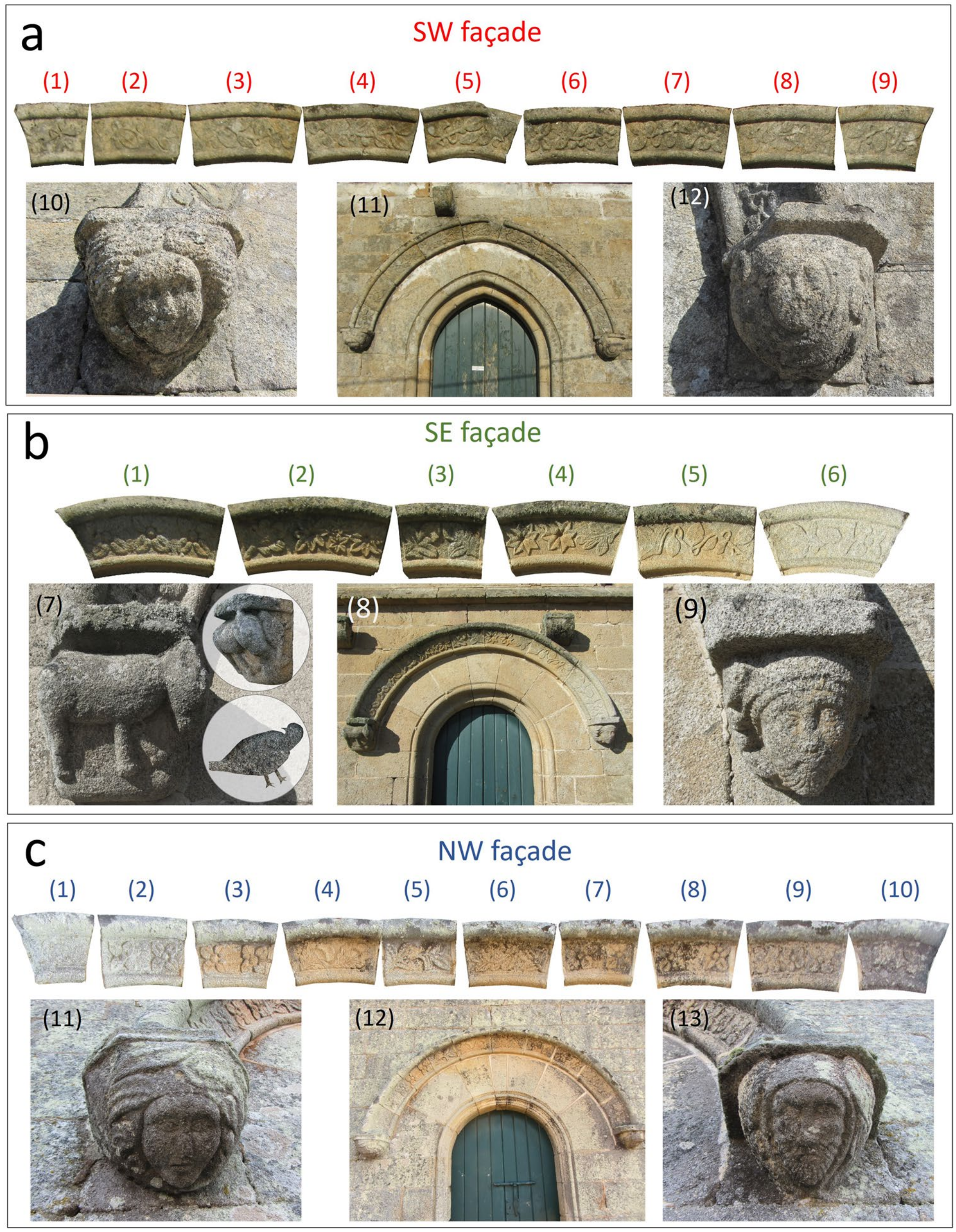


Fig. 3 Doors and chambranles of Nossa Senhora de Guadalupe Church of Mouçós e Lamares. **a** SW façade. (a1–a9):Nine wedge-shaped ashlars that constitute the chambranle. The ornamental motifs are vegetal: a stem from which leaves and flowers sprout. (a10) A female head is carved in this bracket, (a11) General view of the main door of the church (SW façade). (a12) A female head with hair adorned with flowers is carved in this bracket. **b** SE façade. (b1–b6) Six wedge-shaped ashlars that constitute the chambranle. The ornamental motifs are vegetal: detached flowers and leaves, without a stem joining them (b (1–4)), and a stem from which leaves and flowers sprout (b (5, 6)). (b7) A lamb and a dove are sculpted on this bracket. (b8) General view of the door in the SE façade. (b9) A male bearded head is sculpted on this bracket. **c** NW façade. (c1–10) Ten wedge-shaped ashlars that constitute the chambranle. The ornamental motifs are vegetal: flowers and flowers with leaves. (c11) A female head decorated with vegetable leaves is carved in this bracket. (c12) General view of the door in the NW façade. (c13) A male bearded head is sculpted on this bracket

The rear façade (NE) of the nave has a 5-pointed starry rose window, and an upper gabled cornice crowned by a Latin cross. The rear façade of the apse has a coat of arms, and the vertex of the cornice that forms the gabled roof is crowned by a cross with a Jesus Christ, all sculpted in granite. There is a sculpted flower in the rear intersection between the vertical and horizontal boards of the cross.

The NW façade of the nave has a semi-circular arch door formed by 7 voussoirs (Fig. 3c (12)). The door has an archivolt and is marked by a chambranle composed of 10 wedge-shaped ashlars with two archivolts, the lower one being smaller than the upper one, which protrudes more from the façade. Between the archivolts, the ashlars show a decoration of separated tetrapetal flowers and leaves. The right end of the chambranle has a bracket decorated with a male head with beard, and the left end of the chambranle has a bracket decorated with a female head (Fig. 3c (11–13)). These sculptures are facing the ground. Above the chambranle and along the NW façade there are nine brackets with no ornament (but with mason's marks) that supported a formerly existing wooden ceiling, and above them, there is a protective cornice for the beams of it (Fig. 2d).

On the upper level of the NW façade, there are two rectangular flared windows with an archivolt on the outer perimeter and 26 sculpted corbels, supporting the upper cornice on which the roof tiles rest (Figs. 2d and 5).

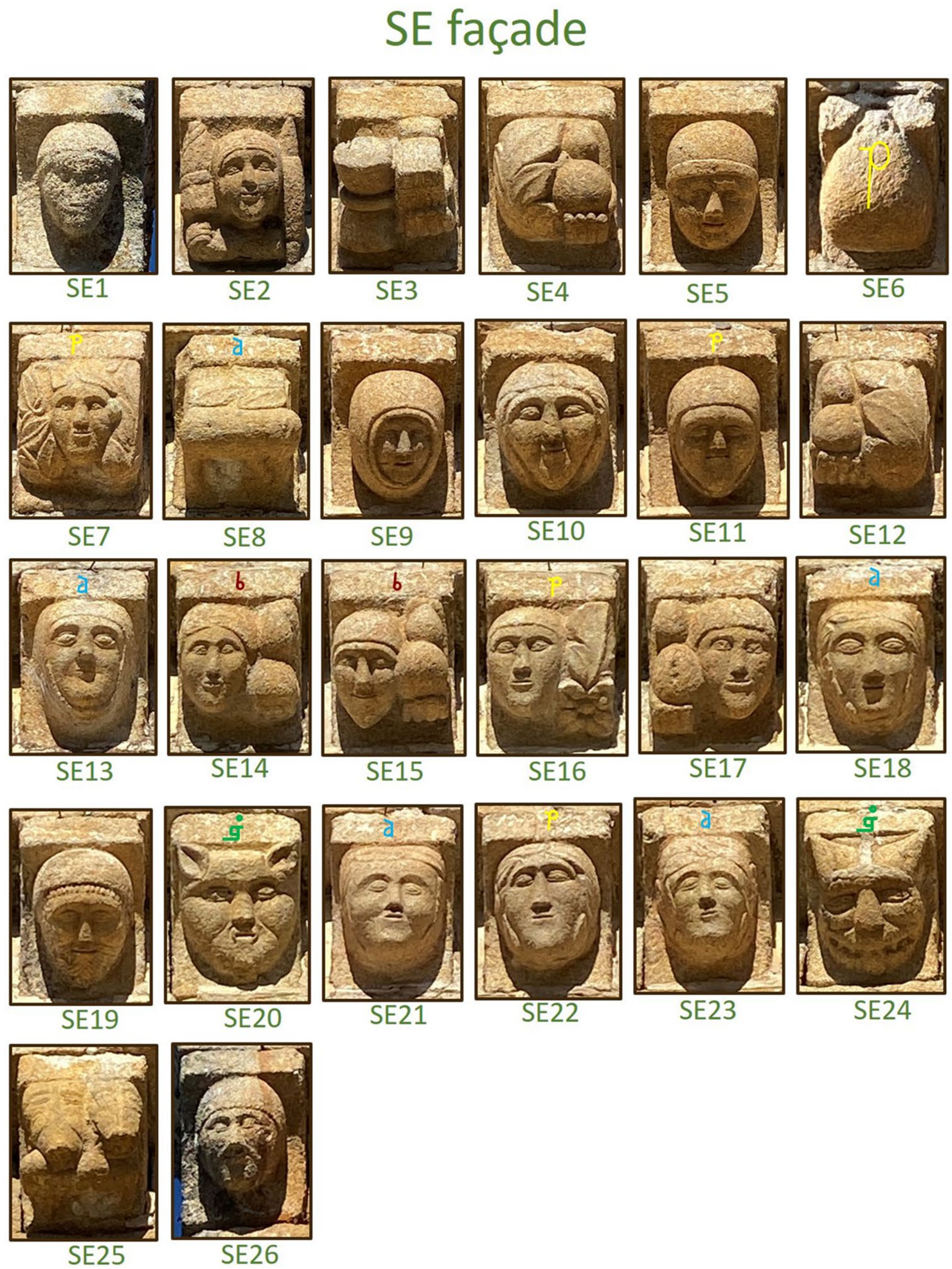


Fig. 4 Corbels from the SE façade of Nossa Senhora de Guadalupe Church of Mouçós e Lamares. Note that the corbels are arranged from the rear façade to the front. SE1 human head; SE2 female spinner; SE3: Flax bundle (left) and flax hatchel/comb, a tool used to separate the flax fibers in the process of making linen (right); SE4 and 12: Vine leaf and a hand holding a bottle gourd (*Lagenaria siceraria*); SE5, 9, 11, 13: Head of a women with headdress; SE6: Amphora; SE7: Head of a woman bordered by leaves; SE8: Lamb and leaves; SE14, 15 and 17: Head of a woman with headdress and a hand holding a bottle gourd (*Lagenaria siceraria*); SE16: Head of a woman with headdress, a tetrapetal flower and a leaf; SE10, 18, 21, 22, 23: Head of a woman with headdress and leaves; SE19 and 26: Head of a bearded man; SE20 and 24: Fantastic beast head; SE25: Two dog heads with one prey

Geological Settings

Vila Real area is the result of a complex assemblage history of continental collision and extension. It is in the Galiza Trás-os-Montes Zone (GTMZ), near the limit with the northern part of the Central-Iberian Zone (CIZ), in the Iberian sector from Variscan belt (Garcia 1987; Cruz et al. 2016). The Variscan belt was produced by the convergence and collision between Laurussia and Gondwana, after the closure of the Rheic Ocean. GTMZ is characterised by siliciclastic metasedimentary and metavolcanic rocks, interpreted as the outermost part of the Gondwana continental margin. What once were sediments accumulated in the Tethys sea basin and metamorphosed with the magmatic intrusions of the Variscan orogeny (Hildenbrand et al. 2021). That is, several continental blocks collided, resulting in the main event of the Iberian lithosphere's formation (García-Arias et al. 2018). Variscan granites intruded the autochthonous metasedimentary formations of Desejosa and Pinhão (Cambrian) and Marão (Ordovicican) from Douro Group (Schist–Metagreywacke Complex) (Coke et al. 2003; Gomes and Almeida 2003; Noronha et al. 2012; Pozo-Antonio et al. 2019) producing the mountainous relief that

Fig. 5 Corbels from the SW façade of Nossa Senhora de Guadalupe Church of Mouçós e Lamares. Note that the corbels are arranged from the rear façade to the front. NW1: Bishop's head with his miter. Note that this head is the only one that is horizontal; NW2: Head of a bearded man; NW3 and 25: Head of a man without beard; NW4: Tetrapetal flower; NW5 and 15: Lamb; NW6: Drum; NW7, 8, 12, 14, 16, 20, 21, 22 and 23: Head of a bearded man; NW9: Woman showing off her genitals; NW10: Dog head with a prey in its mouth; NW11, 18, 19 and 24: Fantastic beast head; NW13: Cat's head; NW17: Wild boar's head; NW26: Head of a bearded man and a hand holding an unidentified object

exists in the Trás-os-Montes area. Finally, the erosion and denudation of the rocky massifs produced exfoliation joins and the entry of meteoric fluids that altered the upper part of the plutons. As a result, alteration processes occur such as the sericitization of feldspars.

Different types of two-mica syntectonic granites from Variscan Vila Real composite massif occur in the surrounding areas of Nossa Senhora de Guadalupe Church (Fig. 6). The two-mica granite term is used almost synonymously with “peraluminous”, alluding to the very common appearance of muscovite in alumina-oversaturated granitoid rocks. This classification based on granite origin, two-mica granite belongs to S-type granite which is formed by sedimentary protolith (Clarke 1981).

Nossa Senhora de Guadalupe Church is located over a small-size intrusive two-mica granite (Sanguinhedo granite), which has a medium to fine grain size with colours varying from gray to yellowish when it is altered. It outcrops on the tops of hills, on slopes; it occurs in the form of blocks and does not show substantial faciological variation.

Vale das Gatas granite outcrop is located to the east of the church. It is a two-mica granite porphyroid of coarse-medium crystal size, characterised by the presence of elongated and oriented feldspars (Freire-Lista et al. 2022a). Lamares granite is

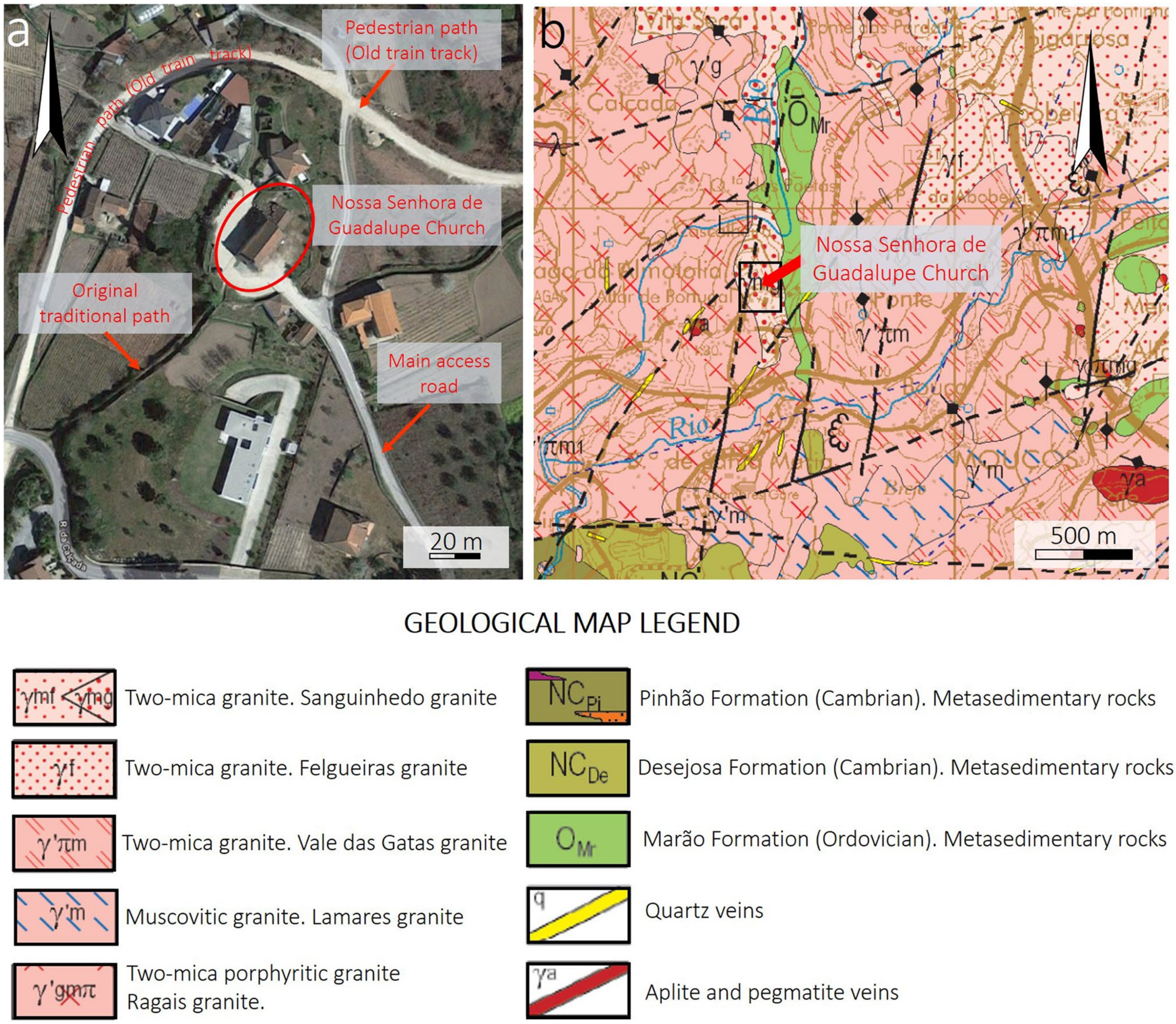


Fig. 6 Location maps. **a** Google Earth map of Nossa Senhora de Guadalupe Church and its surrounding area. The accesses to the church, the main road, a pedestrian path and the traditional path lined with granite walls can be seen (data: SIO, NOAA, US Navy, NGA, GEBCO. Image: Landsat/Copernicus). **b** Geological map of Nossa Senhora de Guadalupe Church area

visible to the south; it is a muscovite granite with sparse biotite, medium crystal size, few phenocrysts and tourmaline. Ragais granite is present to the west of the church, it is a two-mica granite with a medium crystal size and porphyritic tendency. Felgueiras granite is located approximately 1 km to the northeast. It is also a two-mica granite of fine crystal size, with scattered feldspar crystals (Fig. 6). Metasedimentary rocks of Marão Formation (Ordovician) outcrop to the east. Marão Formation has basal quartzites with metaconglormeric levels alternating with phyllites and metapsamites. Some quartzite levels have disseminated magnetite and fine ferrous banks. Locally, tertiary–quaternary sediments cover granites and metasediments.

Countless historical quarries exist in the area. These quarries are usually superficial, and their granite is evidencing frequently altered, a yellowish colour (Iñigo et al. 2013; Junique et al. 2021). Traditionally, the houses of Trás-os-Montes were built on the quarry itself. In other words, traditional houses had a basement or lower part of the house that originated when the stones were extracted for the construction of the walls. The back of the apse and the nave of Nossa Senhora de Guadalupe church are also founded on the Sanguinhedo granite outcrop.

Material and Methods

A documentary investigation has been carried out to determine the renovations of Nossa Senhora de Guadalupe Church. In addition, a glyptographic analysis has been carried out to identify mason's marks, and a petrological inspection "*de visu*" has been performed to determine the building granites. For the characterisation of the main building granite, the façades have been surveyed using automated digital photogrammetry and by performing a petrographic evaluation "in situ" of the ashlars. Once the main building granite was identified, a geological survey was carried out to locate its historical quarry.

Glyptographic analysis (Guedes 2019) has consisted in identifying all the mason's marks on the three visible façades of the nave (SE, NW and SW). Once the marks have been identified, colours have been assigned to each of them to map all the ashlars of the three façades, thus marking each ashlar with a colour assigned to its mason's mark. Light blue: Protogothic letter "a"; Red: Protogothic letter "b"; Violet: Protogothic letter "d"; Yellow: Protogothic letter "d"; Green: Protogothic abbreviation for "ergo"; Dark blue: Sign with three lines forming two inverted right angles; Black: Cross; Magenta: Square; Blown: Right angle. This mapping has been done over several days at different times of the day, since the angle of solar light incidence conditions the visibility of the mason's marks.

Granite samples have been obtained from the original historical quarry, allowing the petrophysical characterisation of the main building granite (Sanguinhedo granite) and of a granite identified in a few ashlars (Vale das Gatas ganite). Six cubic samples of $5\times5\times5$ cm ±0.5 have been cut from each granite at low speed (120 rpm) and low strain to calculate the granite's hydric properties (effective porosity, water absorption, bulk density and capillarity water absorption) and petrophysical properties (ultrasound wave velocity and colour) (Fig. 7).

Effective Porosity, Water Absorption and Bulk Density

The cubic samples of the building granites were tested for effective porosity (Pe), water absorption capacity (in %) and bulk density (ρb) according UNE-EN 1936 following these equations:

$$Pe\ (\%) = [(Ws - Wd)/(Ws - Wh)] \times 100 \quad (1)$$

$$Water\ absorption\ (\%) = [(Ws - Wd)/(Wd)] \times 100 \quad (2)$$

$$\rho b\ (Kg/m^3) = [(Wd)/(Ws - Wh)] \times 100 \quad (3)$$

where Wd is the weight of the dry specimens (after oven-drying at 70 °C and desiccation for 30 min), Ws is the weight of the 24-h water-saturated sample, and Wh is the weight of the sample submerged in water.

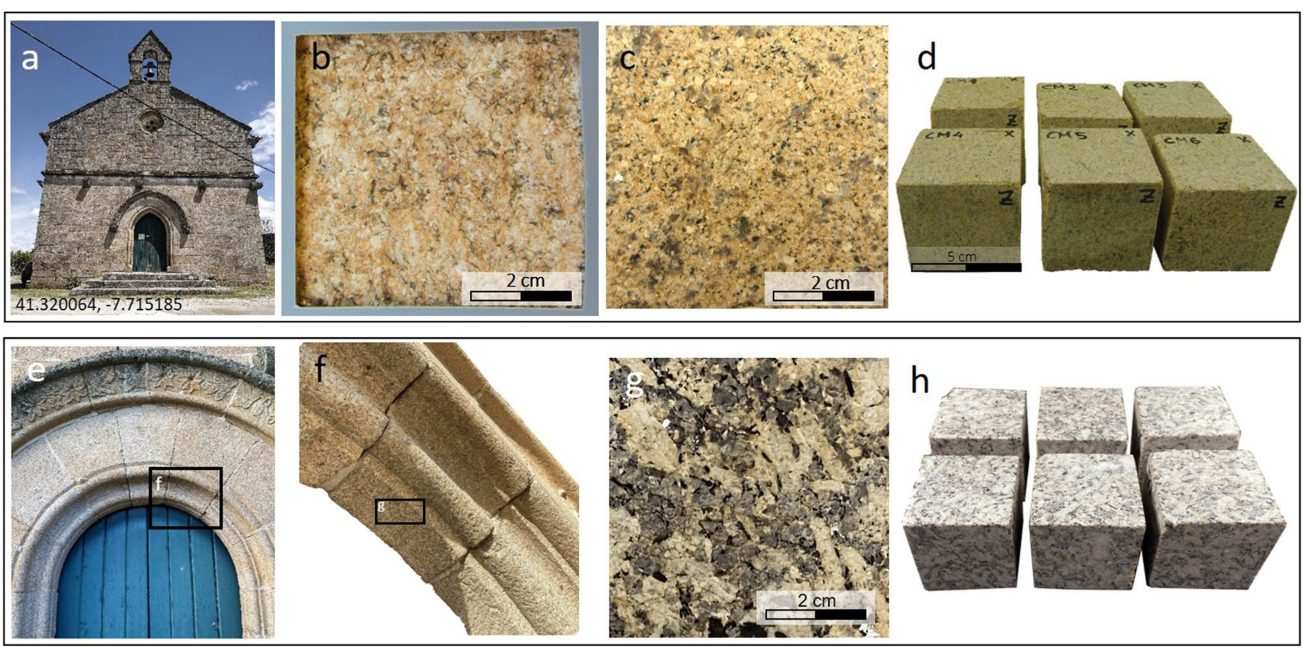


Fig. 7 Heritage stones of Nossa Senhora de Guadalupe Church. **a** Façade of Nossa Senhora de Guadalupe Church. **b** Surface "in situ" of an ashlar of the main building granite. **c** Polished surface of the main building granite from the historical quarry. **d** Six cubes of the main building granite obtained from the quarry to run petrophysical and hydric analysis. **e** Voussoir sculpted in Vale das Gatas granite on the SE façade. **f** Detail of the voussoir. **g** Polished surface of the Vale das Gatas granite from a historical quarry. **h** Six cubes of the Vale das Gatas granite used for petrophysical and hydric analysis

Capillarity Water Absorption

The capillarity test was conducted following European standard UNE-EN 1925, with slight modifications. The specimens were weighed after drying (md) to a precision of 0.01 g and the area of the bases (expressed in m^2) was calculated to a precision of 0.1 mm (Freire-Lista and Fort 2017).

The granite specimens were placed in a tank with a 3 ± 1 mm film of water. The tank was then lidded with an air-tight seal to prevent evaporation. The specimens were periodically weighed to determine the amount of water absorbed during 34-h trial, finding the mean for each group of three specimens. The 24-h water absorption coefficients (weight of water gain per area by time) were calculated for the building granites.

Ultrasonic Pulse Velocity

Ultrasonic pulse velocity (Vp) was measured on each of the six cubes of each building granite in the three orthogonal directions, using the mean of four consecutive measurements of each face of the cubes as the accepted value.

Vp was measured with CNS Electronics PUNDIT equipment (precision: ± 0.1 µs) following UNE-EN 14,579. The 1 MHz transducers (11.82 mm in diameter) were affixed to the surface with a carboxymethyl cellulose paste and water to enhance the transducer-stone contact. Vp is a portable non-destructive technique, with an analytical sensitivity that enables the detection petrophysical changes not currently visible on the surface of the stones.

Colour

Colour analysis in building materials (Prieto et al. 2010; Freire-Lista et al. 2021) is an essential analysis for the verification of historical quarries, location of replacement stones (Rozenbaum et al. 2008; Graue et al. 2011) and evaluation of construction phases. The colour was assessed with an X-Rite colorimeter (model 964), with 45°/0° geometry and specular component included, D65 illuminant and 8 mm aperture.

The colour of the building granites of Nossa Senhora de Guadalupe Church was measured in six specimens of Sanguinhedo and Vale das Gatas granite. It was measured after oven-drying at 70 °C to a constant weight. Ten colour measurements were taken in each sample, and the mean was calculated. Colour was expressed using the three chromatic coordinates of CIE-L * *a* **b* * parameters, following UNE-EN 15,886: luminosity (L*), red to green coordinate (*a* *) and blue to yellow coordinate (*b* *).

X-Ray Diffraction

For the XRD analysis about 1–5 g of granite from the historical quarry were pulverised to 50 µm to use in a D5000 SIEMENS X-Ray Diffractometer operated at 40 kV and 30 mA to determine the mineralogical composition of the main building granite. The measurements were performed in a range between 2 and 68 degrees with an interval of 0.02 and 2 min in continuous mode.

Petrographic Microscopy

Two thin sections were made for the petrographic characterisation of the building granites of Nossa Senhora de Guadalupe Church. To prepare the thin sections, after cutting samples with a low-speed saw, they were polished with sandpaper and progressively smaller diameter-size diamond spray (from 6, 3 to 1 µm of grain diameter). The thin sections were observed under a polarisation microscope Leica DM4500 P, equipped with a digital FireWire Camera Leica DFC 290 HD that worked with the Leica application suite software LAS 4. Two micromosaics (parallel and crossed Nicols) were made with more than 200 microscopic images each. The petrographic properties were obtained through the optical microscopy study of thin sections following UNE-EN 12,407.

Roughness of the Ashlar Surface Finishes

The surface finishes of Sanguinhedo and Vale das Gatas granite ashlars have been studied from their surface topographies. For the measured surface to be the most representative, three ashlars have been selected from the South façade, whose surface is less altered because they are protected under the chambrana. In this sense, a voussoir carved in Vale das Gatas granite from and another in Sanguinhedo granite (RVG and RMG1 respectively) have been selected (Fig. 8a). The surface roughness of a carved Sanguinhedo granite ashlar was also measured on the South façade (RMG2, Fig. 8a). The surface finishes of the ashlars used to wall up the apse windows (RSG, Fig. 8c) and the surface finishes of the ashlars used in the extension of the apse (RAG, Fig. 8c) have also been studied.

The surface topographies of the ashlars have been obtained with a MEL M2DW laser profilometer connected to a laptop through the Ethernet-BlueBox (López et al. 2020; Rodríguez et al. 2023). The sensor has been mounted on a wooden structure that allows it to move in a straight line parallel to the reference plane that rests on the surface to be measured (Fig. 8). The wooden structure has some marks that allow the scaling of the longitudinal movement that exists in the path of the sensor. The profiles (height and intensity of the image) of each track are saved in a computer application developed for this purpose. Subsequently, this file was processed and filtered to obtain a topography with the heights (Z) in a

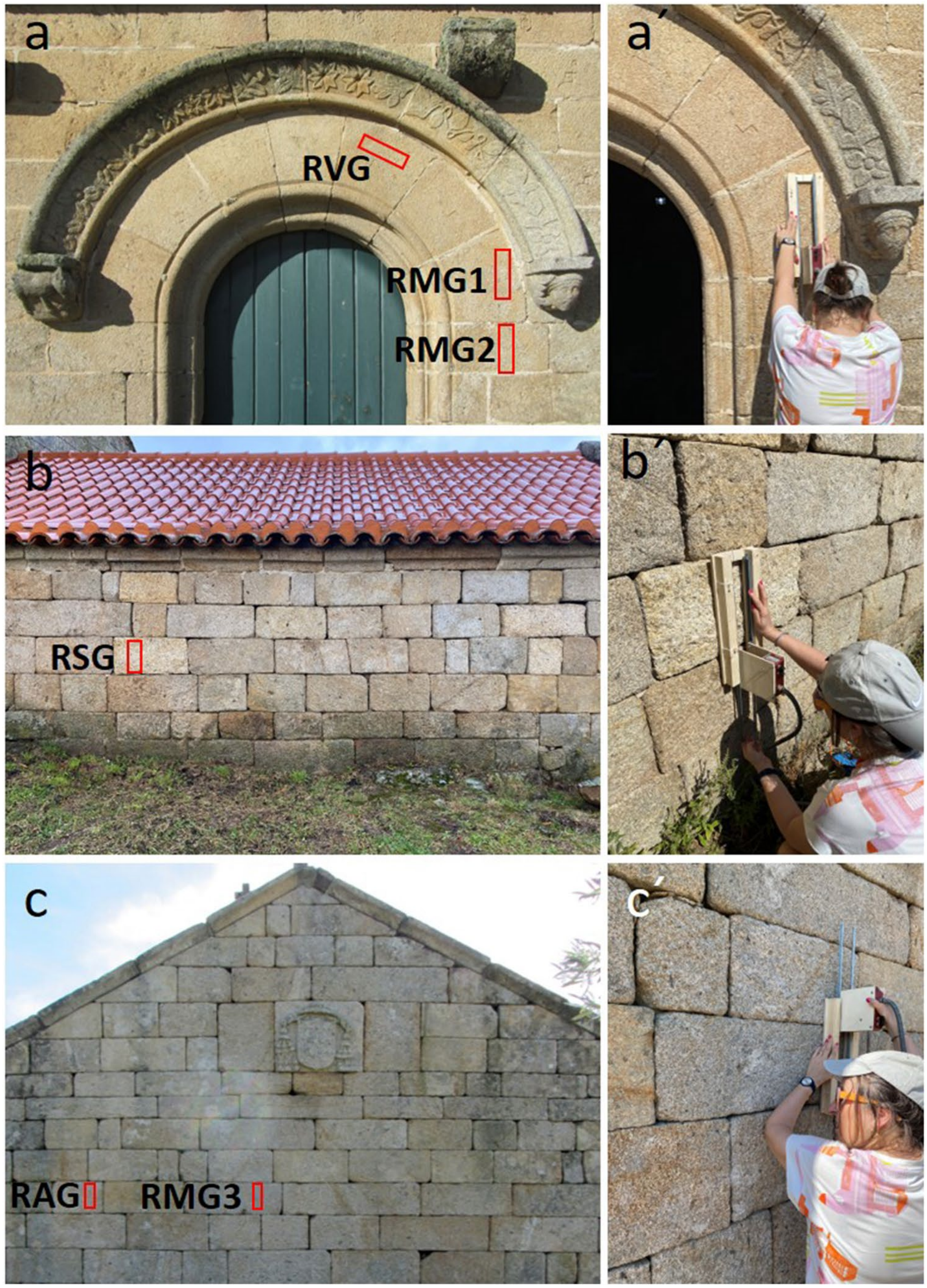


Fig. 8 Location of the roughness measurements of the surface finishes of six representative ashlars of Nossa Senhora de Guadalupe Church. **a** South façade of the nave. (RVG) Surface roughness measurement area of a voussoir carved in Vale das Gatas granite. (RMG1) Surface roughness measurement area of a voussoir with a mason's mark carved in Sanguinhedo granite. (RMG2) Surface roughness measurement area of an ashlar with a mason's mark carved in Sanguinhedo granite. **b** South facade of the apse. (RSG) Surface roughness measurement area of an ashlar that covers the window. **c** Rear façade of the apse (East). (RAG) Surface roughness measurement area of an ashlar carved in Sanguinhedo granite for the extension of the apse (ashlar without stonemason marking). (RMG2) Surface roughness measurement area of an ashlar with a mason's mark carved in Sanguinhedo granite

regular mesh (XY) of 20 mm × 200 mm and an intensity image of the same size. Surface roughness measurements were made from topography values. For each of the ashlars analysed, at least 5 measurements of an area of 4000 mm^2 were made.

Areal roughness was obtained according to the standard UNE-EN ISO 25178–2:2013 in terms of the arithmetical mean height, Sa, and the root mean square height, Sq; by levelling the measured surfaces and fitting them to a plane. Values of Sa and Sq parameters were calculated for all valid measurements to obtain the mean values and the standard deviation.

To compare the differences between the finishes, the Abbott-Firestone curves (bearing area curve) were plotted. Mathematically, it is the cumulative probability density function of the height of the surface and is a graphical version of all the height parameters (which are the moments of the probability distribution).

Results

Historical Changes in Nossa Senhora de Guadalupe Church

Vestiges of whitewashing can be seen on the main façade of the Church. The use of lime became widespread, in addition to be a constructive element, as an antiseptic whitewash to mitigate epidemics between the sixteenth and seventeenth centuries. It was mandatory to whitewash some churches, hospitals and public buildings in the eighteenth century (Glória 2016). Therefore, Nossa Senhora de Guadalupe Church has been whitewashed and today there are traces of this whitewash (Fig. 9a). The same whitewash that covered its ashlars and sculptures also served to protect them through the centuries.

The roof is usually the element most vulnerable to deterioration, which is why the roof of Nossa Senhora de Guadalupe Church has undergone changes that affect the granite ashlars in one way or another. Originally, the roof was made of curved Arabic tiles, with the shape of a truncated cone channel, by placing roof tiles in a channel (concave side up) and on its two sides, the roof tiles were installed in a convex-side-up position. This type of tile was a part of the church for several centuries. Possibly flat Marseille tiles were placed in the twentieth century (Fig. 9a'), (Marseille tiles were marketed for the first time in France in 1840). This tile is rectangular, and the lower edge is rounded. One major side has a slot and flap on the other side of the adjacent tile so that they can be assembled linearly (Fig. 9b–d).

A new triumphal arch (pointed arch) which gives way to the apse and wider than the original, was opened inside the church, in the rear wall of the nave, and the apse obtained its current rectangular shape possibly in 1529. Battlements with triangular merlons installed on the NW and SE façades of the apse (Fig. 9a', b, c).

The Portuguese General Directorate for National Buildings and Monuments repaired the church roof in 1969. The roof of the apse was changed, removing its battlements and covering the roof of the NE wall of the apse with granite (Fig. 9c, c'). Possibly the windows of the apse's SE façade (now bricked up) were opened at this time (Fig. 9a', c).

The lower part of the SE façade of the apse (exterior pavement) was cemented to prevent infiltration in the first half of the 1980s (Fig. 9c). Mixed tiles were installed on the roof in 1988. These types of tiles have a curved and a flat shape, which acts as a drainage channel, with a lateral projection so that they fit together and can be assembled. The windows on the SE façade of the apse were removed in 1988 (Fig. 9c, c'). Improvements to the nave's roof and consolidation and waterproofing works were done in

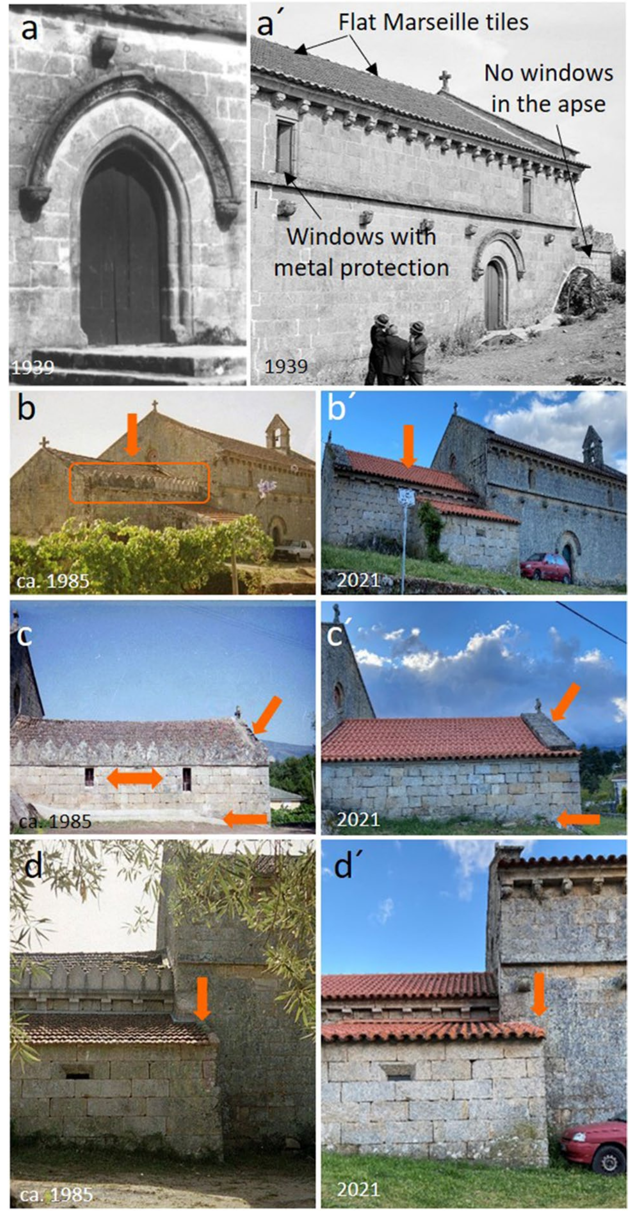


Fig. 9 Historical and 2021 photographs showing some of Nossa Senhora de Guadalupe Church renovations throughout the twentieth and twenty-first centuries. **a** 1939 photograph showing remnants of the whitewash that covered the façades of the church. (a') 1939 photograph showing the Marseilles flat roof tiles introduced between the late nineteenth and early twentieth centuries. The windows of the nave were protected with a metal net. Note that no windows are visible in the apse wall. **b** and (b') General view of the church from the northeast. b: Photograph from circa 1985. Battlements with triangular merlons of granite in the apse (crowning the SE and NW façades). Note that the triangular merlons located immediately above the sacristy have less biological colonisation, so they are possibly more recent. The tiles are of Marseille type. **c** Photograph from circa 1985. Detail of the apse with triangular-shaped battlements and two windows in the SE façade of the apse. (c') Bricked up window in the apse with a different granite of original building stones. No triangular merlons are in the apse. **d** Photograph from circa 1985. Sacristy with a flat-tile roof and zinc plate flashings. (d') 2021 photograph. Mixed tiles on the rooftops

1992. Zinc plate flashings were installed on the back of the sacristy and apse in 1996. Today, there are no zinc plate flashings nor cement pavement on the SE façade of the apse (Fig. 9c').

Glyptography

Mason's marks are both inside and outside the church walls. The results obtained in the glyptographic study of the exterior part of the SE, NW and SW façades are summarised as it follows.

Nine mason's marks have been identified and a protection mark on the left lintel of the main door (SW main façade) (Fig. 10). Most of these mason's marks correspond to protogothic letters, as indicated above. The mason's marks have been revealed in all the elements of the visible façades of the church, except in the chambranle. The mason's marks are carved in visible areas, approximately in the center of each ashlar. On the voussoirs, they are located on the low concave part or on the front. On the corbels, the mason's marks are at the top front rectangle (Fig. 4). The corbel SE6 has a mark in its central part (Fig. 4). Therefore, nine stonemasons have worked throughout the church construction process and most have worked both in the elaboration of ashlars, voussoirs and corbels. All have mostly carved the same type of stone: the Sanguinhedo granite that outcrops in Nossa Senhora de Guadalupe Church. A voussoir of the door of the SE façade and some other ashlars and corbels (all of them with the stonemason mark "P", represented in yellow) are carved in Vale das Gatas granite; it outcrops near Nossa Senhora de Guadalupe Church.

Two construction phases have been distinguished, based on the mapping of the mason's marks. In the first phase, the stonemasons represented by the colours yellow, red, green, light blue, magenta, violet and black participated. In the second construction phase, the stonemason represented by the magenta colour (L-shaped polygon mason's mark) is not present, and the stonemason represented by the dark blue colour (two inverted right angles mason's mark) appears (Fig. 11a). The stonemason represented by the light blue colour ("a" letter) has also worked mainly in the upper part of the church. Figure 11b shows the percentage of work that each stonemason did, according to the mapping. According to this mapping, the stonemason represented by the letter "P" (yellow) was the one who carved the greatest number of ashlars (Figs. 11c, 12), and also, he was the one who carved the greatest number of voussoirs and corbels.

The motifs represented in the corbels of Nossa Senhora de Guadalupe Church are described in Figs. 4 and 5 and analysed in Table 1. They are mostly made up of male heads on the NW façade and female heads on the SE façade.

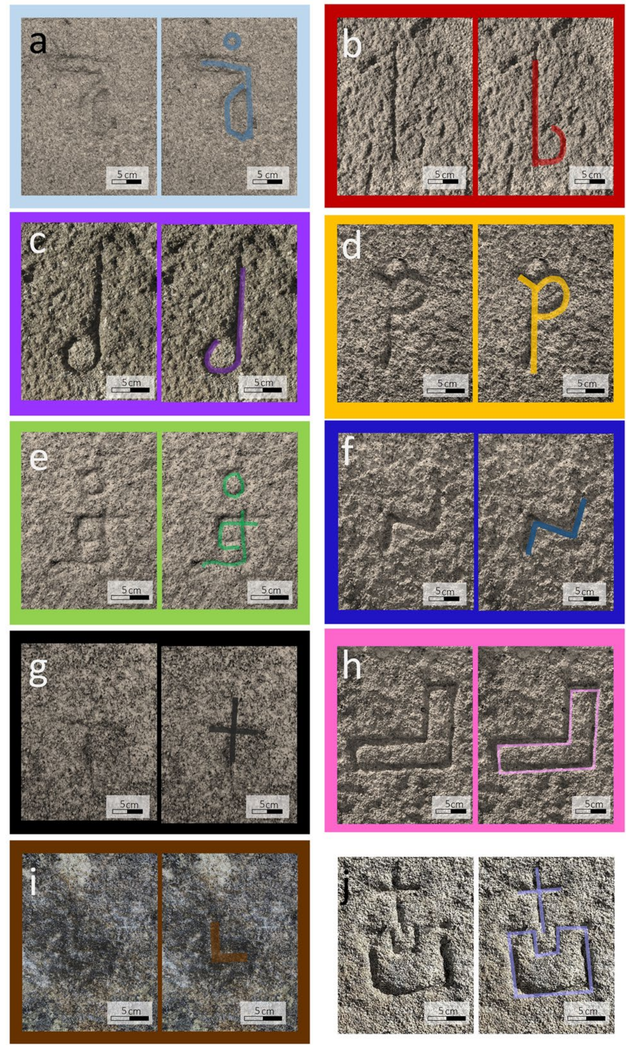
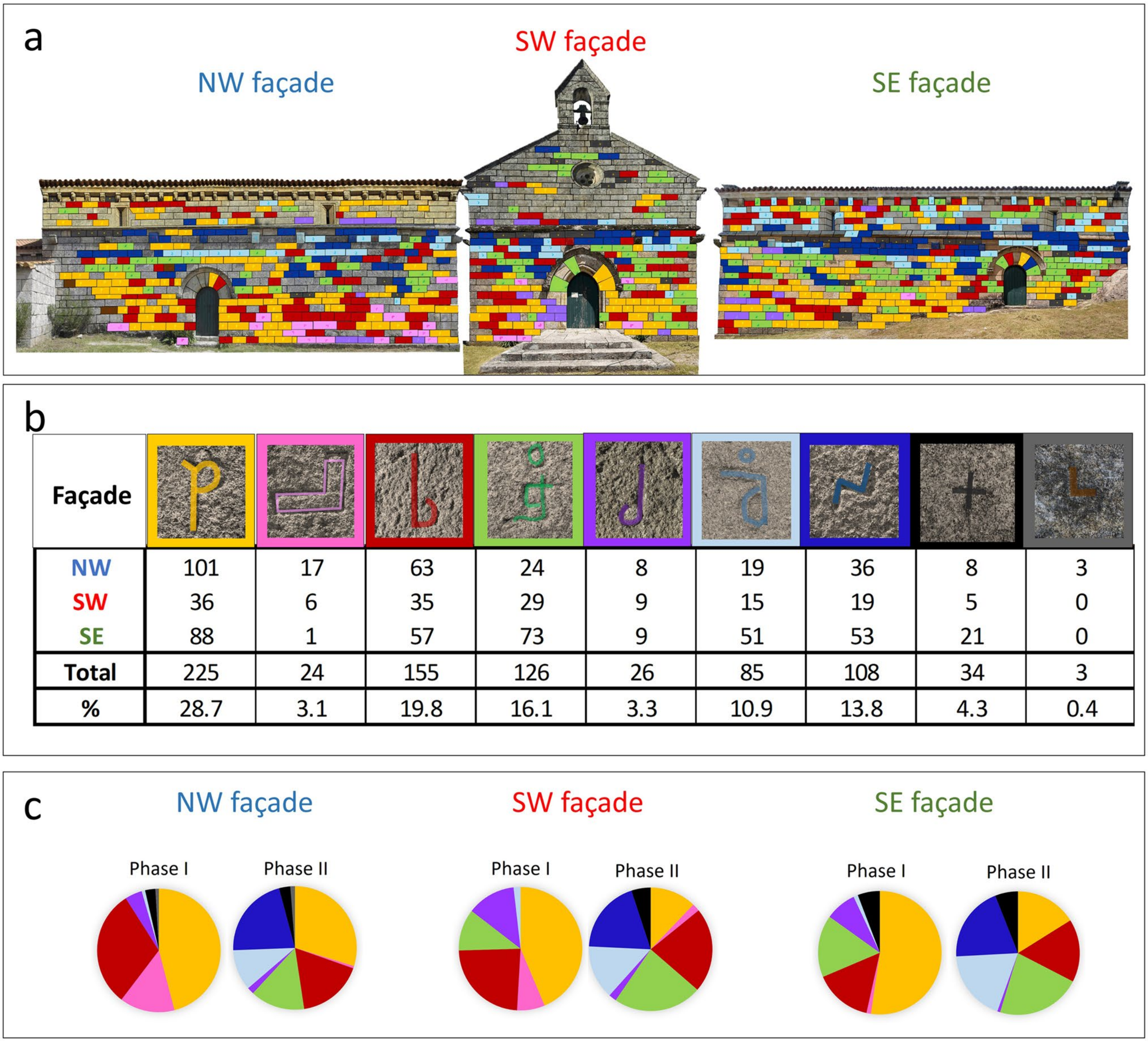


Fig. 10 Mason's marks identified in Nossa Senhora de Guadalupe Church. **a** Protogothic letter "a". **b** Protogothic letter "b". **c** Protogothic letter "d". **d** Protogothic letter "p". **e** Protogothic abbreviation for "ergo". **f** Sign with three lines forming two inverted right angles. **g** Cross. **h** L-shaped polygon. **i** Right angle. **j** Protection mark on the lintel of the main door. Note that there is only one mark of this type in Nossa Senhora de Guadalupe Church

The chambranles have been the only constructive element of the nave of Nossa Senhora de Guadalupe Church in which no mason's marks have been observed. Therefore, the glyptographic analysis has been based on the type of vegetal decoration sculpted in their wedge-shaped ashlars (Fig. 3). The ashlars were grouped into three types of decoration: flowers and leaves set on a stem; detached single flowers and leaves; and tetrapetal flowers (Fig. 13). In this way, the SW façade chambranle has decoration based only on flowers and leaves set on a stem; the SE façade chambranle has the three types of plant decoration, and the chambranle on the NW façade has tetrapetal flowers, and single flowers and leaves (Fig. 13).



Façade									
NW	101	17	63	24	8	19	36	8	3
SW	36	6	35	29	9	15	19	5	0
SE	88	1	57	73	9	51	53	21	0
Total	225	24	155	126	26	85	108	34	3
%	28.7	3.1	19.8	16.1	3.3	10.9	13.8	4.3	0.4

Fig. 11 Glyptographic analysis of the mason's marks of Nossa Senhora de Guadalupe Church. **a** Mapping of the mason's marks on the three façades. **b** Number of mason's marks on each façade. **c** Analysis of mason's marks in each construction phase of Nossa Senhora de Guadalupe Church, showing the percentage of ashlars installed by each stonemason

X-Ray Diffraction

The peaks identified in the X-ray diffractogram of Sanguinhedo granite (Fig. 14) correspond to the following minerals:

i) Anortite (An): It is a calcium aluminosilicate ($CaAl_2Si_2O_8$). It is a type of plagioclase in which calcium accounts for more than 90% of metal ions;
ii) Biotite (Bt): Silosilicates of iron and aluminum K (Mg, Fe)$_3$AlSi$_3$O$_{10}$ (OH, F)$_2$, minerals from the micas group;
iii) Quartz (Qt): Quartz is a mineral composed of silica (SiO_2);
iv) Microcline (Mc): It is a potassium aluminosilicate, a mineral from the group of potassium feldspars ($KAlSi_3O_8$);
v) Muscovite (Ms): It is a potassium and aluminum aluminosilicate (KAl_2 ($AlSi_3O_{10}$) $(OH)_2$. Mineral from the micas group;
vi) Orthoclass (Or): It is a potassium aluminosilicate, a mineral from the group of potassium feldspars ($KAlSi_3O_8$).

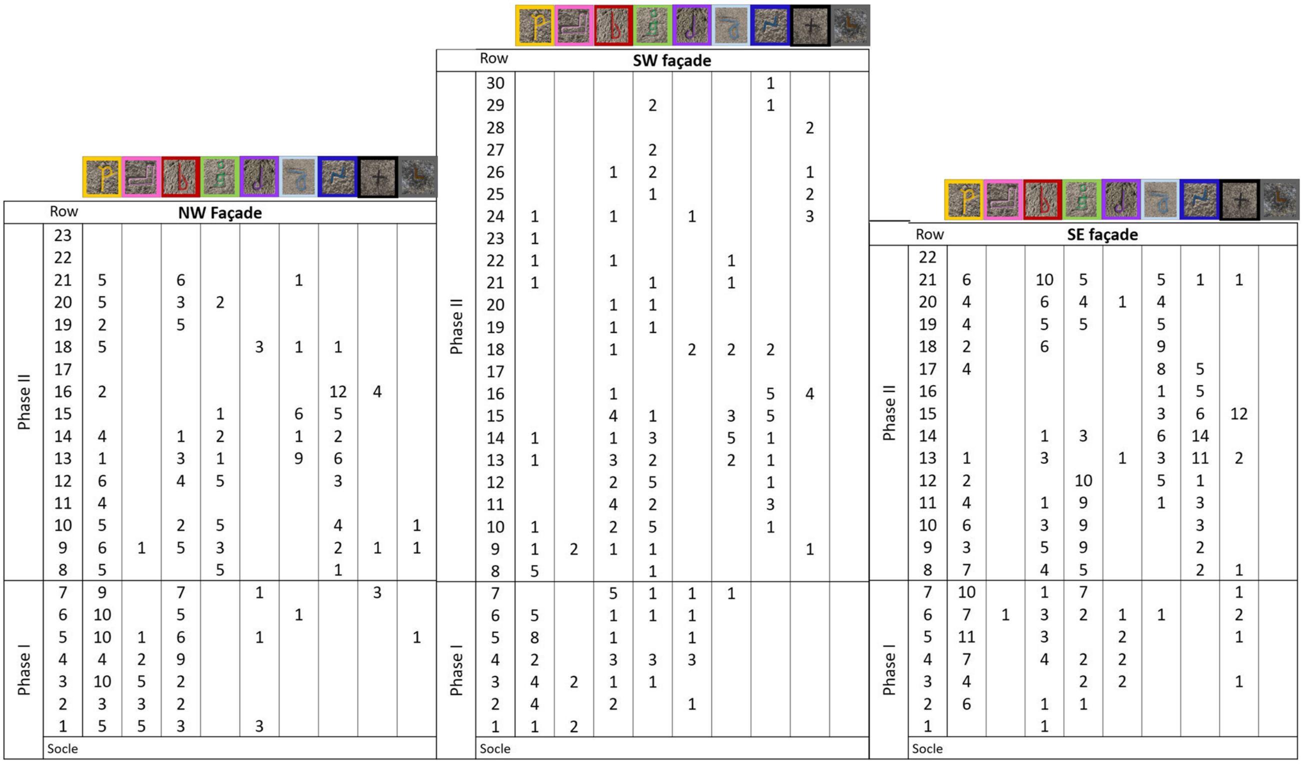


Fig. 12 Number of mason's marks in each granite row of Nossa Senhora de Guadalupe Church

Table 1 Motifs represented in the corbels of Nossa Senhora de Guadalupe Church

NW façade			SE façade		
Sculptural representation	Quantity	%	Sculptural representation	Quantity	%
Male head	13	50	Female head	16	62
Female head	1	4	Male head	1	4
Exhibitionist female	1	4	Animals	2	8
Animals	5	19	Vegetable motifs	2	8
Vegetable motifs	1	4	Fantastic beast head	2	8
Fantastic beast head	4	15	Object (book, amphora)	2	8
Object (musical instrument)	1	4	Human head (unidentified sex)	1	4

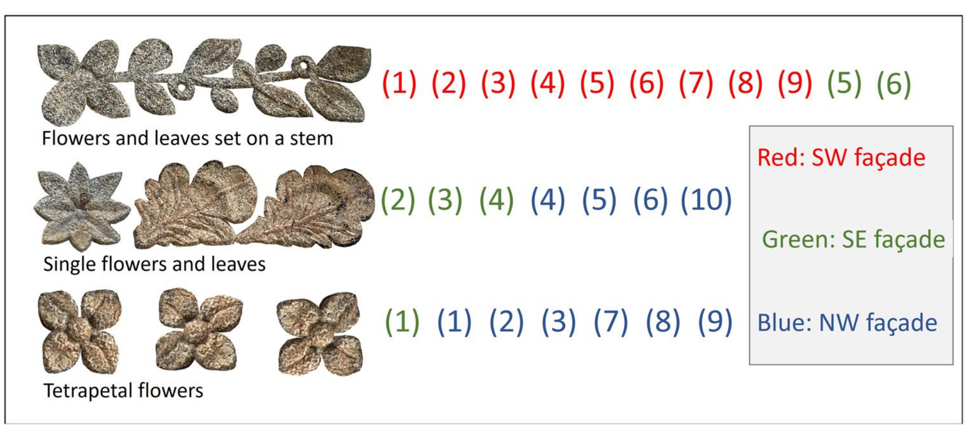


Fig. 13 Glyptographic analysis of the wedge-shaped ashlars that constitute the chambranles. Note that the numbers correspond to the wedge-shaped ashlars present in the chambranles in Fig. 3

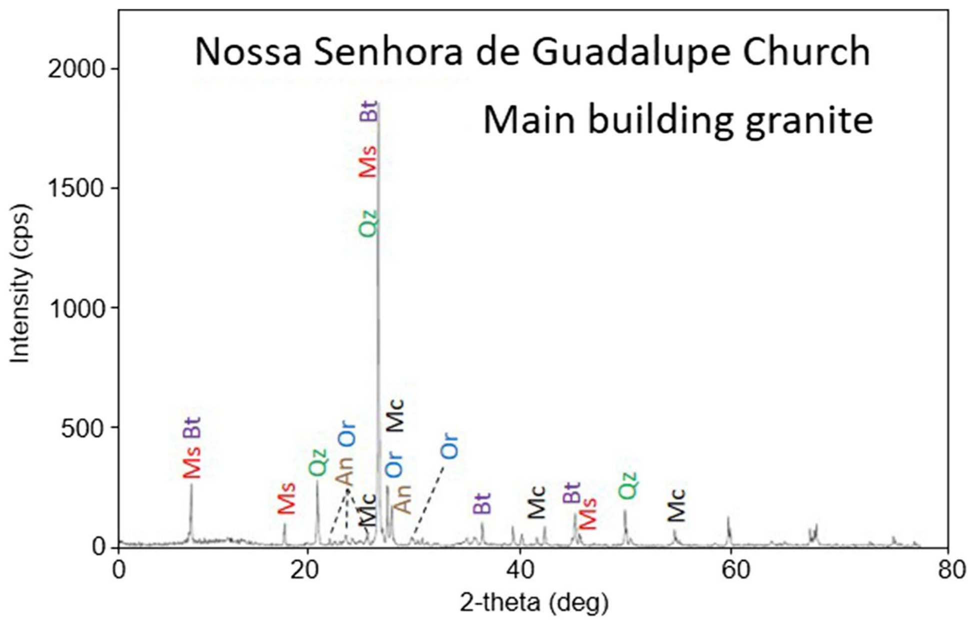


Fig. 14 XRD results of the main building granite of Nossa Senhora de Guadalupe Church. An Anorthite, Bt Biotite group minerals, Qtz Quartz, Mc Microcline, Ms Muscovite, Or Ortoclase

Petrographic Microscopy

The major petrographic differences between the main building granite (Sanguinhedo granite) and the Vale das Gatas granite, which appears in few ashlars and voussoirs, are textural. Sanguinhedo granite has medium-fine and homogeneous crystal size (Fig. 15a, a'). Biotite nodules are observed macroscopically. Vale das Gatas granite has medium-coarse crystal size, porphyritic with elongated and oriented feldspars (Fig. 15b). Both granites are described below.

Sanguinhedo granite has medium-fine crystal size, predominantly isotropic. Its mineralogical composition is homogeneous. The granite is made up of K-feldspar, plagioclase, quartz, biotite and muscovite, as primary minerals. Secondary minerals are biotite, muscovite and sericite. This rock is (QAPF) classified as monzogranite.

K-feldspars up to 4 mm, subhedral microcline up to 3 mm are observed. K-feldspar occupies a QAPF percentage of approximately 35%. Slight K-feldspar sericitisation (alteration) is observed (Fig. 15a').

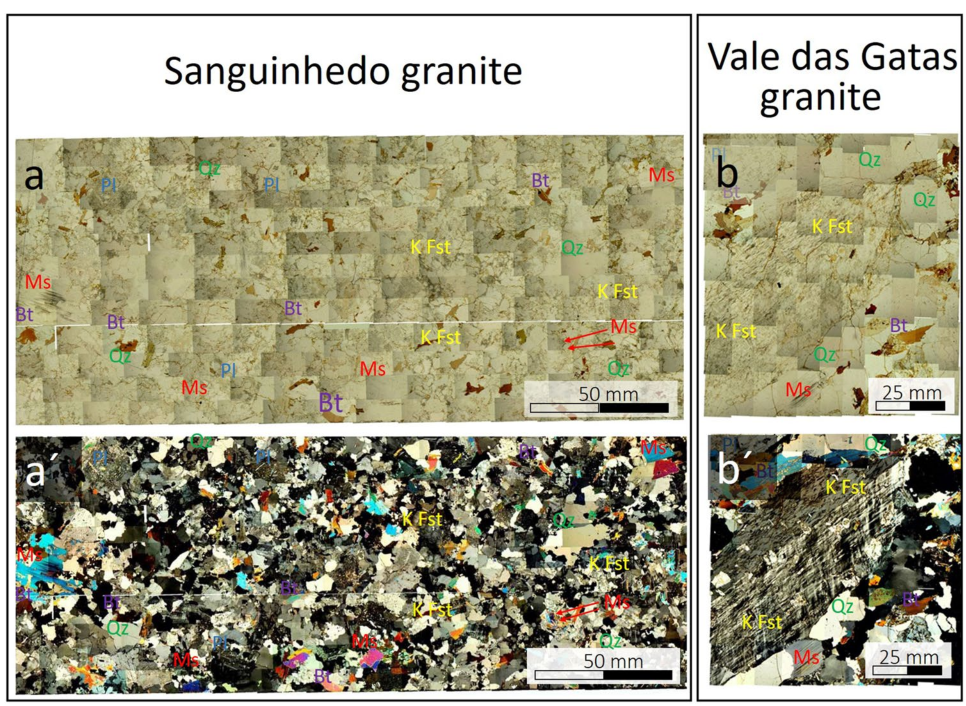


Fig. 15 Petrographic micromosaics of the Sanguinhedo (**a**) and Vales das Gatas (**b**) granites. Microscopic appearance with parallel (**a** and **b**) and polarised light (**a'** and **b'**). Bt Biotite-group minerals, K-Fs Potassium feldspar, Ms Muscovite, Qz Quartz, Pl Plagioclase

Plagioclase has subhedral tabular and anhedral habits (Fig. 15a') with crystal size varying between 0.5 and 5 mm. The central part of anorthite crystals, particularly the larger crystals, are frequently altered to sericite. Plagioclase occupies a QAPF percentage of approximately 40%.

Quartz is anhedral and has poikilitic texture (inclusions of biotite) with crystal sizes varying between 0.1 and 5 mm. It is primarily interstitial to the feldspars, but some occur in the granulated and recrystallized rims and veinlets around and within the feldspars, while some occur simply as inclusions in the feldspars. Quartz occupies a QAPF percentage of approximately 25% (Fig. 15a').

Muscovite occurs in primary and secondary forms (Fig. 15a'). Primary muscovite has tabular habits (euhedral and subhedral). Its crystal size can reach 5 mm; the edges of the crystals are well delimited. In its secondary form, muscovite occurs as sericite formed by feldspar alteration.

Biotite has primarily euhedral to subhedral tabular habits (Fig. 15a') and secondarily form scales; both types have dimensions not exceeding 2.8 mm. Primary biotite displays chloritisation, which can be partial (at the edges) or total (Fig. 15a').

Vale das Gatas granite has medium-coarse crystal size, it is porphyritic with elongated and oriented feldspars. The granite is made up of K-feldspar, plagioclase, quartz, biotite and muscovite, as primary minerals. Secondary minerals are biotite, muscovite and sericite. This rock is classified (QAPF) as porphyritic monzogranite.

K-feldspars include large, sometimes porphyritic microcline perthites (up to 2 cm across) and smaller (1–5 mm and less) microcline (Fig. 15b'). Within these feldspars, there are small quartz crystals. K-feldspar sericitisation occurs mainly in bands longitudinal to the crystals. K-feldspar occupies a QAPF percentage of approximately 35%.

Plagioclase has subhedral tabular and anhedral granular habits (Fig. 15b') with crystal size varying between 0.4 and 5 mm. Sodic plagioclases occur as discrete crystals and as exsolved phases in K-feldspar. Some of the patch perthites look very much like replacement perthites. The plagioclases, particularly the larger crystals show varying degrees of sericitisation. Albite shows twinning. Plagioclase occupies a QAPF percentage of approximately 35% (Fig. 15b').

Quartz is anhedral and has poikilitic texture (inclusions of small biotite crystals). Crystal sizes are between 0.1 and 5 mm. It is primarily interstitial to the feldspars, but some occur in the granulated and recrystallized rims and veinlets around and within the feldspars, while some occur simply as inclusions in the feldspars (Fig. 15b, b'). Quartz occupies a QAPF percentage of approximately 30%.

Muscovite occurs in primary and secondary forms. Primary muscovite has tabular habits (euhedral and subhedral). Its size can reach 5 mm; the edges of the crystals are well delimited. In its secondary form, muscovite occurs as sericite formed by feldspar alteration (Fig. 15b, b').

Biotite has primarily euhedral to subhedral tabular habits with zircon inclusions. Primary biotite displays chloritisation, which can be partial (at the edges) or total.

Effective Porosity, Water Absorption and Bulk Density

As shown by the petrophysical property values in Table 2, the values obtained for effective porosity (Pe), water absorption and bulk density (ρb) are very similar for the two building granites of Nossa Senhora de Guadalupe Church. Both show a yellowish colour, being slightly darker the granite of Vale das Gatas.

Capillarity Water Absorption

The two granites show different capillarity water absorption. Sanguinhedo granite capillarity coefficient is 3.7 g/m^2 s$^{1/2}$ and Vales das Gatas granite capillarity coefficient is 2.4 g/m^2 s$^{1/2}$. Figure 16 shows the absorption of water over time.

Roughness of the Ashlar Surface Finishes

The areal roughness parameters, Sa and Sq, of the surface finishes in different ashlars of Nossa Senhora de Guadalupe Church are similar, except for the ashlar used to brick the windows of the south facade of the apse. The obtained values are presented below:

-Voussoir carved in Sanguinhedo granite (with a mason's mark) (RMG1): Sa = (0.3022 ± 0.0062) μm; Sq = (0.382 ± 0.011) μm.
-Ashlar carved in Sanguinhedo granite (with a mason's mark) (RMG2): Sa = (0.4812 ± 0.0052) μm; Sq = (0.6021 ± 0.0062) μm.

Table 2 Petrophysical properties of the main building granite of Nossa Senhora de Guadalupe Church (Sanguinhedo granite) and petrophysical properties of Vale das Gatas granite

Property	Sanguinhedo	Vale das Gatas
Effective porosity (%)	3.2 ± 0.3	3.5 ± 0.2
Bulk density (kg/m^3)	2 566 ± 61	2452 ± 35
Water absorption (%)	1.2 ± 0.3	2.1 ± 0.3
Ultrasonic pulse velocity (m/s)	2920 ± 98	2550 ± 153
Lightness, L*	55.02 ± 5.1	42.76 ± 5.4
Red-green value, a*	4.67 ± 0.98	2.82 ± 0.85
Blue-yellow value, b*	16.82 ± 1.61	11.27 ± 2.9

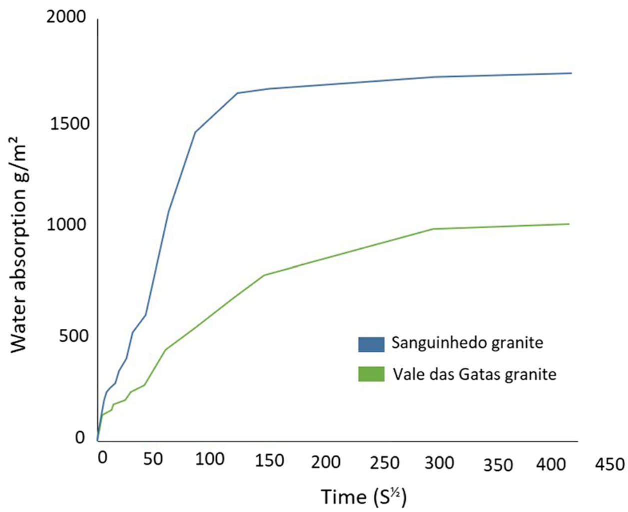


Fig. 16 Weight gain per area over time for Sanguinhedo and Vale das Gatas granites

-Ashlar carved in Sanguinhedo granite used to widen the apse (RMG3): Sa = (0.4649 ± 0.0049) µm; Sq = (0.5858 ± 0.0080) µm.
-Ashlar carved in Sanguinhedo granite (with a mason's mark) used in the apse (RAG): Sa = (0.6028 ± 0.0091) µm; Sq = (0.747 ± 0.011) µm
-Ashlar used to brick the apse windows (RSG): Sa = (1.457 ± 0.034) µm; Sq = (1.792 ± 0.033) µm.
-Voussoir carved in Vale das Gatas granite (RVG): Sa = (0.383 ± 0.026) µm; Sq = (0.501 ± 0.040) µm.

The roughness parameters of the surface finish of the original Romanesque ashlars are very similar, regardless of whether they are carved in Sanguinhedo granite (RMG1 and RMG2) or Vale das Gatas granite (RVG), while the roughness parameters for the ashlars carved later are different, especially the value of RSG as it can be seen in Fig. 17 which represents the Abbot-Firestone curves of the different ashlars. The ashlars used to wall up the windows of the apse show a roughness that is very different from the original surface finish.

Discussion

Several monuments with carved mason's marks exist in Portugal (Silva 1868; Sousa 1965; Charréu 1995, 1997; Gandra 2001; Marques et al. 2010; Liberato et al. 2017; Silvério 2017; Vidal Gonçalves 2021), but there are no documentary records of the mason's marks factory of how mason's marks were carved. Therefore, the processes at work must be inferred by studying the buildings in which they occur. The correlation between masonry types, construction phases, stone types and mason's marks is necessary in historical and archaeological investigations because it allows to reconstruct the process building (Alonso Ruiz 2009; Khamisy 2017). Masons marks reveal important historical and ethnographic findings that will be very useful for the appreciation of monuments.

The petrographic characterisation of heritage stones (Costa 2015; Torrero et al. 2015; Piovesan et al. 2019; Freire-Lista 2020) enables the location of the historical

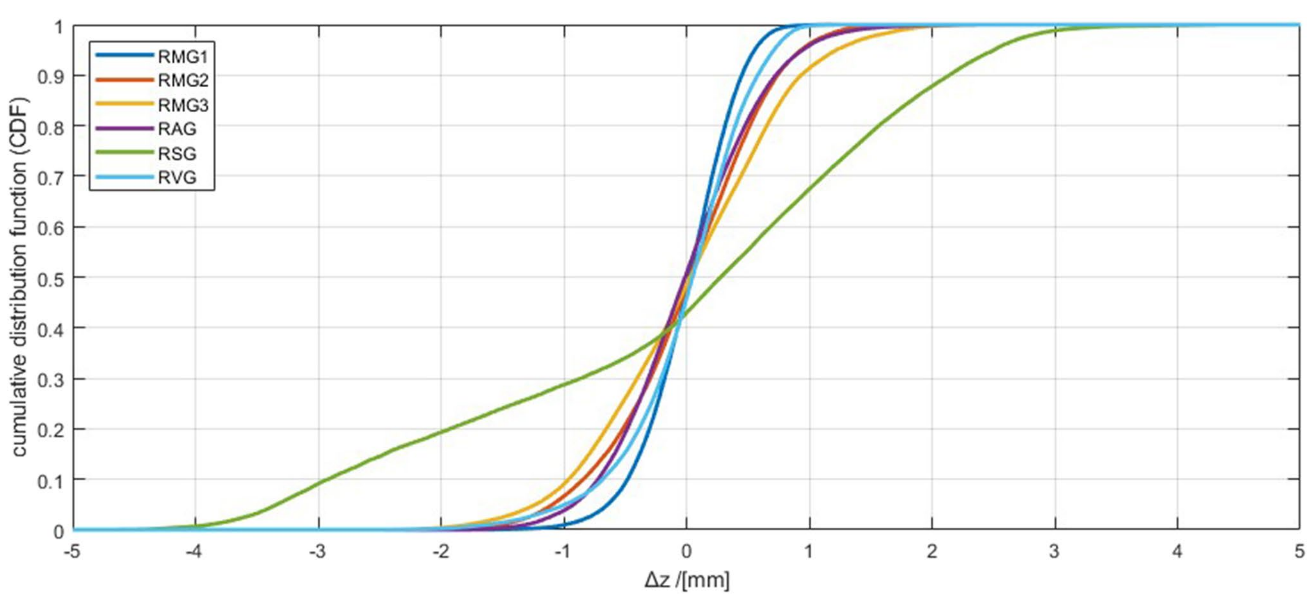


Fig. 17 Abbott-Firestone curves (bearing area curve) for the six surface roughnesses of the measured ashlars. Mathematically, it is the cumulative probability density function of the height of the surface and is a graphical version of all the height parameters

quarries (Franzini et al. 2001; Gaied et al. 2010) from which the stonemasons extracted the best heritage stones for the construction of monuments (Bloxam 2011; Gutierrez 2011; Stefano and Paolo 2017; Prosser 2019).

Crystal size determines the durability of building granites. Granites with larger crystal size are more susceptible to decay (Freire-Lista et al. 2015a, b). The stonemasons who built Nossa Senhora de Guadalupe Church chose well the main building stone (Sanguinhedo granite), as it is close to the church and its petrographic characteristics make it ideal for carving. Vale das Gatas granite has a larger crystal size, which makes it difficult to be carved and reduces its durability. However, a voussoir located in the SE façade, and some other elements were carved in Vale das Gatas granite (Figs. 6, 7).

According to petrographic and petrophysical observations, the two granites are slightly altered. The effective porosity, water absorption and capillary absorption coefficient are high when compared to currently commercial building granites (Vázquez et al. 2010). However, it should be considered that this work is focused on heritage stones, which were obtained from surface quarries (Navarro et al. 2022), where granite is easier to extract, cut and carve. These altered granites usually present yellowish colours. Therefore, they are altered and their petrophysical properties are reduced (Anovitz et al. 2021; Zhu et al. 2021).

Probably, the mason's marks were carved in the masonry workshop adjacent to the church itself, before the ashlars were placed in their final location, since some mason's marks are rotated 180°, especially those represented with the colour dark blue (sign with three lines forming two inverted right angles). The mason's marks are placed in highly visible places, which may indicate that the stonemasons were interested in having their marks visible once the ashlars were installed. This suggests that payment was most likely received after placement of the ashlars.

The stonemasons represented by the colours yellow, dark blue, green and red carved, in addition to ashlars, voussoirs and corbels. This may imply that these stonemasons had a greater skill for sculpture. The stonemason represented with the letter "p" (yellow) carved the largest number of ashlars, voussoirs and corbels. This may indicate that this stonemason was the most experienced, or even the master builder.

There is a clear iconographic difference between the corbels of the two façades: most of the anthropomorphic heads on the NW façade are male heads in a static position. These corbels are presided by a male head with a miter (the only one that is positioned longitudinally to the nave). It possibly represents a bishop or an archbishop of Braga, since bishops founded, donated and protected churches in their dioceses. They were members of the nobility and made their subjects attend churches located in their lordships or linked to their lineage.

The SE façade is characterised by the symbolic representation of daily work carried out by women. Corbels 4SE2, 4SE3 and 4SE4 represent a spinner, a linen bundle with a flax hatchel, and a bottle-gourd with a vine leaf respectively. In other words, they represent the main agricultural products of the region, together with wool (4SE8). Textiles (linen) and oil were made from flax and its seeds were used for medicinal purposes (Grau Sologestoa 2012; Pastor de Togneri 1998; Peña-Chocarro et al. 2013).

It is worthwhile noting that many corbels refer to wine, with the representation of women carrying wine containers (bottle-gourds) and the repeated motifs of bottle-gourds and vine leaves. This evidences that wine production in the Tras-os-Montes e Alto Douro region is much older than the demarcation stated by the Marquis of Pombal (eighteenth century) (Lourenço-Gomes et al. 2015) and that women in the Middle Ages were empowered and engaged in financially profitable work.

Animals were examples that explained human behaviour in the Middle Ages, and animal iconography represented religious truths (Boehm and Holcomb 2001). Several animals are represented in Nossa Senhora de Guadalupe Church. Lambs (Figs. 3b (7), 5NW5 and 5NW15) were related to the sacrifice of Christ. Christ is the Lamb of God and the good shepherd who takes care of the flock. Doves (Fig. 3b (7) are honest because they remain faithful to their partner even after death. They symbolize fidelity and marriage and, at the same time, like all winged animals, spirituality, the sublimation of instincts, the elevation, the transcendence and the detachment from the earth. It is one of the symbols most used by the Catholic religion to capture the Holy Spirit, Jesus Christ, the Church, the faithful and the soul of the innocent. Dogs (Figs. 5NW10, 4SE25) were associated with fidelity and collaboration with humans; they were ideal hunting companions, representing vigilance and patience. They also were represented in medieval sepulchral tombstones (Freire-Lista 2016). Wild Boars (Fig. 5NW17) symbolised the devil, since their devastating passage through fields and vineyards was associated with the idea of destruction. They could also represent strength and struggle, they were like a totem animal in Celtic culture of NW Iberia. (Simões de Abreu 2021). Cats (Fig. 5NW13) had positive values in Celtic culture. They represented the capacity of introspection and analysis to know the truth and to unmask false prophets, and knowledge the Otherworld. But since the middle of the Middle Ages, a negative view of this animal was accentuated, especially of black cats, which culminated at the end of the late Middle Ages with its identification with witchcraft and Satanism (Carvajal González 2014).

Glyptographic analysis indicates that the current apse was built after the nave. The apse only has some reused ashlars with the same type of mason's marks that have been described in the nave. The rest of the apse ashlars do not have mason's marks.

In addition, the current apse not has corbels with sculpted figures. This means that the current apse does not correspond to the same construction phase as the nave, the original apse was renovated. Bessa (2006) indicates that there are corbels in the apse of Nossa Senhora de Guadalupe Church. However, the image that she shows corresponds to the nearby São Tiago de Folhadela Church. This church was built with Prezandãis granite, characterised by stains of Fe oxide caused by the alteration of pyrites. A corbel of Sanguinhedo granite was found in the nave of São Tiago de Folhadela Church. Possibly, this corbel comes from the original apse of Nossa Senhora de Guadalupe Church and has been reused in the remodeling of São Tiago de Folhadela Church (Freire-Lista et al. 2022a, b).

The author of Memórias de Vila Real (1721) attributed the foundation of Nossa Senhora de Guadalupe Church to the abbot Pedro de Castro in the 1530 s (the wall painting on the apse is dated 1529). It was based on the coat of arms of D. Pedro de Castro, painted inside the church and sculpted outside the apse (São Payo 1999; Bessa 2006; Cardoso Rosas 2010). Therefore, possibly the abbot Pedro de Castro financed the opening of the triumphal arch and the remodeling and expansion of the apse. Possibly, at the time when the pointed triumphal arch located inside the church, between the nave and the apse, was built. Some remaining ashlars from the opening of the arch were reused to build the current rectangular apse.

The dearth of ornamental motifs (circumscribed to the chambranles and their brackets, oculus, corbels and crosses) is a typical characteristic of the late Romanesque. The main door in the shape of an ogival arch announces the beginning of the Gothic period and manifests an incipient and experimentalist Gothic, typical of the thirteenth century. Most of the mason's marks of Nossa Senhora de Guadallupe Church are protogothic letters, common in the Iberian Peninsula in the twelfth to thirteenth centuries (Marcos García 2017; Caravias Ordaz 2018). The stonemasons may have been illiterate (some wrote symbols instead of letters) and could have been imitating letters that they had seen in inscriptions from another era. Glyptographic analysis does not allow for absolute dating. However, optically stimulated luminescence (Sanjurjo-Sánchez and Montero Fenollós 2012) is a reliable technique that allows dating of mortars. This analysis would provide quantitative data, useful to identify the archbishop present in the corbels of the NW façade and to expand the knowledge of the construction procedures in medieval period. The scientific corpus of historical-cultural heritage of Galicia-North Portugal Euroregion should be expanded to enhance development of tourism. Recognition of the significance of Nossa Senhora de Guadalupe Church will help promote geotourism and geomonumental routes (Del Lama et al. 2015; Freire-Lista et al. 2017; Del Lama 2019; Medina-Viruel et al. 2019) since heritage conservation is a bet for the future generations (Salameh et al 2021), and of Tras-os-Montes e Alto Douro has enormous cultural potential.

Conclusions

The main building granite of Nossa Senhora de Guadalupe Church is Sanguinhedo granite, a medium-fine crystal size monzogranite. The church is built on a promontory of this granite. Therefore, the main historical quarries are inside and near the church.

A small number of granite ashlars from Vale das Gatas has been identified. This stone is a medium-fine-grained monzogranite with feldspar phenocrysts. The outcrops of this granite are approximately 300 m away from the church.

Sanguinhedo granite should be used as replacement granite in future restorations of Nossa Senhora de Guadalupe Church.

The nave of the church is almost preserved as it was originally built. In other words, it has not undergone major modifications since its construction. The apse of the church has been modified, and most of its ashlars lack mason's marks, and ashlars with mason's marks are reused.

Two construction phases have been distinguished in the nave according to the mapping of mason's marks. Nine stonemasons built the façades of Nossa Senhora de Guadalupe Church and six stonemasons participated from the beginning to the end. Six mason's marks are protogothic letters (twelfth–thirteenth century).

Different mason's marks have been identified inside the church. A full glyptographic study would provide more useful information about the church.

The exceptional state of conservation and iconography make this church a unique example of Portuguese rural architecture in the Middle Ages. The well-preserved corbels show the ethnographic reality of Northern Portugal. The iconography of the corbels of the two façades is different. Male heads predominate on the NW façade. On the SE façade most corbels represent women's daily work with allusions to wine. This testifies to the antiquity of wine production in Tras-os-Montes e Alto Douro region. In addition, it suggests that women were empowered and performed financially profitable work in the Middle Ages.

The petrographic analysis has made it possible to locate a corbel from the original apse of Nossa Senhora de Guadalupe Church. This corbel is installed in the nave of the nearby São Tiago de Folhadela Church.

Most of the mason's marks are preserved because of the petrographic and petrophysical properties of Sanguinhedo granite. Further, Nossa Senhora de Guadalupe Church was protected by whitewash during the past centuries, and it was not removed with the projection of abrasive particles.

Roughness parameters provide crucial information on the surface finish of historic ashlars. The surface finish of the replacement ashlars used in monument restorations must have a similar roughness to the original ashlars.

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Data Availability Data available on request from the authors.

Declarations

Conflict of Interest The authors declare no competing interests.

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