GUIDE FOR THE DESIGN, CONSTRUCTION AND MAINTENANCE OF NATURAL STONE FACADES

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Guide for the design, construction and maintenance of natural stone facades

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EDITORIAL

Guide for the design, construction and maintenance of natural stone facades

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PRESENTATION

The architectural accidents occurred nowadays in any type of natural stone facade cladding are mainly caused by the absence of the knowledge needed to correctly interpret the results of the tests run to characterize the material, by some mistakes made in the building design, and above all, by the lack of control during the setting-up.

This guide for the design, construction and maintenance of natural stone facades deals with the three aforementioned pathological causes in order, following a logical process: the study of the stone from laboratory tests, the assessment of the building design proposed by the designer, and the receipt control at worksite of both materials and implementation units.

Instructions about the practical meaning of CE marking, about regulatory and legal aspects related to materials, and about facade maintenance have also been included in this guide.

Furthermore, the last chapter shows the so-called «base price of granite». This is an application that follows the Data Base Standard Exchange Format for Construction (FIEBDC), and allows obtaining the full description and the approximate price of each item of work that has granite.

All this is explained in simple terms, so prescribers can easily understand them, since this publication is principally focused on them.

José Ángel Lorenzo Ramírez
FCTGG Manager

INTRODUCTION

Nowadays, Galicia is unquestionably in the top of raw granite production in Spain. About 800 000 granite blocks are extracted from Galician quarries every year, which means 92 % of the total of Spain. In the same way, Galicia leads granite transformation in Spain. The eleven million square metres of products manufactured in Galicia represent 78 % of Spanish manufactures.

In Galicia, there is high quality raw material and a very advanced transformation industry in technological terms, which is considered the second most important in Europe, and the forth in the world. It is thanks to this why it has had the recognition of the markets, which contributed with relevant economic, social and technological changes for Spanish manufacturers.

Furthermore, it is interesting to emphasize that Galician companies also import raw granite blocks from different countries in order to transform them into manufactured products in their factories. All this has the guarantee of a wide experience acquired after many years working with this exceptional material.

Granite has been widely used in construction thanks to its inherent physical properties and its unquestionable aesthetic qualities. Its field of use includes residential buildings and civil works.

The use of stone for cladding construction is a new conception of the use of this material, which origin lies in a drastic and fundamental change of the traditional massive concept of building vertical faces for a new one, mainly superficial, without any structural function. This new concept starts with Mies van der Rohe.

Nowadays, building facade cladding makes up constructive systems in which natural stone, as well as providing its exceptional aesthetic value, gives many of its features such as facade soundproofing, insulation, durability, and protection against external environmental stresses.

In conclusion, granite ventilated facades are the last step in the evolution of technical advances and in the specialization of the use of this material.

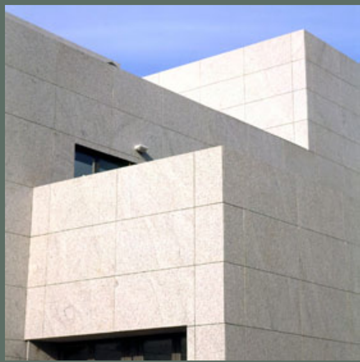
1.

STONE FOR FACADE CONSTRUCTION

Stone is one of nature's most beautiful materials. Each piece stands out for its unique value and good performance over time, leading us back to our ancestor's footprints.

Today, this natural product offers endless design possibilities thanks to new surface finishes, cutting technologies and the broad range of varieties on the market.

Compared to other materials, stone stands out for its high level of resistance and excellent durability

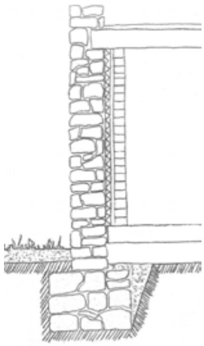


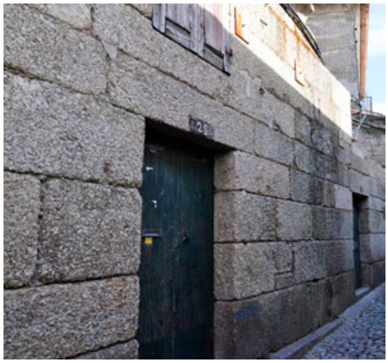
1.1. Brief historic overview

The natural stone load-bearing wall constitutes, as supporting structure, the historic reference for facade's traditional systems.

These facades, which are characterized by their work under compression, support great loads that are transmitted from the wall cope to the foundations. This is a stable and durable solution due to its solidity, which provides an effective insulation thanks to its great thermal lag.

The search for new architectural shapes, the cost saving, and the easiness and quickness of facade assembly came together with the XX century, so a new tendency to lighten constructions by developing steel or concrete frame structures arises. That





Traditional facade wall

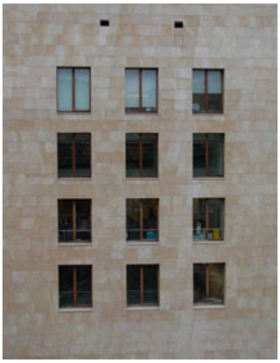
means that the stone loses part of its mass, becoming a mere coating.

Then, the stone self-supporting wall is replaced by frames in which the stone works as coating in the form of slabs, called cladding, giving more slender facades. Nevertheless, there are still many examples of contemporary architecture that uses the whole stone in ashlar or masonry.

The use of stone claddings in facades started in a similar way to the Greco-Roman construction tradition, in which the stone covered low quality works by fixing granite slabs straight to the supporting structure by mortar and anchors. Initially, this was a problem, since they were inserted without taking the mechanical performance of the building into account.

- An internal sheet, called support, which is bore by the building supporting structure. According to its name, this sheet works as a support for the external envelope thanks to an anchorage system.

Facades constructed with different stone varieties



Leaving an air space between cladding and structure to avoid problems created by thermal expansion and rain water was a great progress in this kind of facades. An insulating material is placed later in the air space on the internal support of the building structure in order to improve the thermal insulation.

Then, the solution of the **ventilated facade** was born, which is based on a building principle called «rain screen», developed by G.K. Garden in the sixties. This contemporary facade is made up of:

- A thin external continuous sheet, independent from the internal sheet of the envelope, so it can get distorted at its free will. It is the building external image.

- A ventilated and continuous space, which mission is keeping both the internal and the external sheets ventilated to evacuate the moisture between them.

- A thermal insulation layer adhered to the internal sheet of the envelope.

[1] In 1963, he publishes a study in which he explains how the ventilated facade principle will be useful to prevent the water inlet in the envelopes.

It is important to mention that the ventilated facade improves the traditional one as regards soundproofing, thermal protection, watertightness, stability, and use limitations.

1.2. Natural stone designation

According to the European regulations in force, when dealing with any project, stone should be classified right from the outset from two points of view: a scientific or petrographic classification and a commercial designation or classification

The **scientific or petrographic identification** establishes classification groups with common characteristics, both physical and chemical, in order to provide a basis, not only for commercial designation, but also for laying down prior evaluation criteria on rock performance in different applications.

On the other hand, **commercial designation** is established by the manufacturer according to the **marketing** strategy considered more suitable for each product.

In short, the **rocks most used in construction** are:

- **Granite:** crystalline rock with magmatic origins and a good level of resistance against compression and erosion caused by abrasion, as well as an excellent environmental performance.
- **Marble:** carbonated rock with metamorphic qualities made of calcite or dolomite crystals with a compact and crystalline texture, liable of good polishing. It has a good level of flexural and compression strength and, to a lesser degree, to erosion caused by abrasion.
- **Limestone:** a sedimentary rock made of calcite carbonate crystals but less crystalline than marble. They are frequently presented in different bioclastic varieties with abundance of fossilized shell remains.
- **Sandstone:** a sedimentary rock made of quartz sand, feldspar, etc. bound together by variable composition cement.
- **Quartzite:** a metamorphic rock made of quartz crystals. It is very resistant to erosion caused by abrasion.
- **Slate/phyllite:** a metamorphic rock made of clay sediment. It has a very high level of flexural strength, although some varieties have shearing risk.

1.3. Natural stone varieties

Today, thanks to market globalization, project planners can choose from a broad stone catalogue where they can always find a suitable variety to meet all the needs of their design.

The diversity of colours, tones, textures and finishes offered by this exclusive material makes it stand out from other products with the added characteristic that each piece is unique.

Mosaic of colours and textures

The website www.clustergranito.com includes a list of companies in the cluster of granite, as a reference tool for prescribers. All the necessary information for each company (varieties, finishes, and stone sizes) can be found in it.

1.4. Surface finishes

The stone surface finish constitutes the coat of a facade and represents its hallmark, along with size and petrographic variety.

Surface finishes are always undergoing new developments, because the current techniques of these treatments, as well as the capacity for research of the companies in this matter, progress fast. The most common **surface finishes** are:

- **Polished:** a finish which final appearance is achieved through solutions, waxes, etc., and offers a mirror-like shine appearance.

- **Honed:** finish with variable granulometric grinding wheels which gives a smooth surface with a somewhat matt appearance.

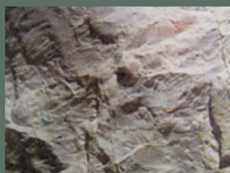
Most important surface finishes

Polished

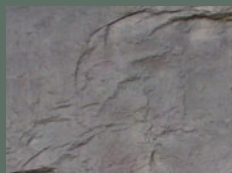
Honed

Bush hammered

Flamed



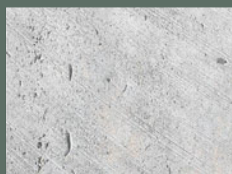
Split



Sheared

Sand blasted

Brushed



Sawn

- **Bush hammered:** it is made by variable geometry bush hammers or spiked wheels that hit the stone surface, giving it a rough surface.

- **Flamed:** achieved by the firing of a blowtorch giving a rough finish by sandstone shattering. It results in a very stable surface without loosening risk.

- **Split:** achieved by cutting up with a shearing machine, which gives a very irregular and rough finish.

- **Sheared:** a natural shearing of the stone given by sedimentation or schistosity planes when the stone has this kind of anisotropies. This way, a finish that occasionally has adhered sandstones with detachment risk results from it, which needs a rigorous control to assess its stability.

- **Sand blasted:** achieved by the firing of a blast of sand giving a rough but smooth appearance to the surface due to the aggregate abrasion

- **Brushed:** a finish similar to sand blasted but, in this case, metallic fiber brushes are used for the final finish.

- **Sawn:** achieved with a diamond wire saw or gang saw.

1.5. Stone advantages for facade construction

Facades constructed with natural stone have many advantages compared to other competing products. Three features entice the use of this material: beauty, excellent durability and design possibilities, which lead to **advantages** such as:

- **Excellent physical properties:** the great flexural strength of the stone makes it an extremely solid construction material, especially granite. The same can be said about anchor strength, which is essential for the durability of a cladding subjected to great stresses.

- **Non-flammable:** natural stone has an A1 Class rating for its fire performance, which classifies the material as «non-combustible, with no reaction even at the highest degree of fire». In the event of a fire, natural stone does not release substances that are harmful to health.

- **Excellent intrinsic features:** stone is the only construction material that remains exactly as it was when extracted from nature, without any chemical changes made to its structure or composition.

- **Different types of roughness and texture:** achieved through several surface finishes that mainly affect the aesthetic result of the facade.

- **Different types of patterns and chromatisms:** achieved thanks to a wide range of sizes, shapes and surface treatments due to the technological development of an industry that never fails to surprise prescribers, presenting them an unlimited range of products that can be adapted to any environment.

- **Possibility of large formats:** as well as some other materials used for facades, stone can offer big size formats.

- **Low maintenance costs:** natural stone is not more expensive than other materials considering the total costs of construction material over a lifespan of thirty years or more. Investment costs are offset by a low maintenance cost and a long lifespan.

- **Contemporaneity:** stone is becoming a widely used material in contemporary construction nowadays. Thanks to modern industrial techniques, it offers a great number of possibilities for architectural design.

- **Sustainability:** the manufacture of stone clearly requires less energy consumption than many other materials such as ceramic flooring or concrete. Stone lifespan is completed with the advantage of having a great reuse capability.

It is estimated that buildings consume up to 50 % of the energy available for the user. In this regard, unlike other materials used for facade cladding, such as ceramics and concrete, natural stone in general, and granite in particular, use less energy thanks to its natural origin with hardly any transformation of the raw materials extracted in the quarries.

Plates cut from a slab

Quarry blocks fragmented in slabs

The table below shows data about the embodied energy of the processes of extraction, elaboration, transport, laying, and even demolition after their lifespan of some of the most common materials in construction.

Material	Embodied energy (kWh/t)
Steel	7 000
Aluminium	28 000
Copper	8 000
Wood	1 000
Glass	2 000
Granite	780

Table 1.1.: embodied energy in construction materials

Ventilated facades are taking on more and more importance in nowadays vertical construction sector thanks to their versatility and, above all, to their energy saving qualities. In this regard, natural stone in general, and granite in particular, creates a facade cladding system quite suitable for any kind of building, such as hospitals, blocks of flats, restored buildings, warehouses, etc.

The **advantages** of the natural stone **ventilated facade** are:

- **Energy efficiency:** 25 % to 40 % reduction of energy used in heating and air conditioning.
- **Cost reduction:** thanks to thermal and fire conditioning and insulation, soundproofing, and waterproofing.
- **Replacement easiness:** dilapidated modules can be easily replaced if needed.
- **Creative freedom:** thanks to the wide model variety.
- **Construction flexibility:** thanks to the mobility provided by the fixing anchor.

1.6. Formats used in facades

1.6.1. Slabs for cladding

Natural stone slabs for external façade claddings are units obtained by cut or shared with a nominal thickness over 12 mm, which can reach big sizes up to 2 m.

This section includes slabs in façade cladding for both adhered and ventilated façades with an air space; that is to say, fixed to the support with mortar or adhesives or with mechanical anchors.

The selection of a slab for cladding is conditioned by the stone characteristics, the bonding material, and the amount of stresses acting in each case.

The **slabs for claddings fixed with mortars or adhesives** need to be smaller than those fixed mechanically, since they are conditioned by the lower support capability these two products have compared to the mechanical anchor. The most common formats are the squared and rectangular shapes, with different sizes: 30 × 30 cm, 40 × 40 cm and 60 × 40 cm. The slabs are recommended not to be higher than 60 cm at ground level, and not to weight more than 40 kg.

The selection of the bonding material will depend on the porosity of the stone and the support. So, cement mortars need materials with a higher porosity than the ones used with adhesives. This is related to the type of joint. In the case of the mortar, it is a physical joint, which needs the material to allow the penetration of the cement crystals in its pores when hardened. While in the case of the adhesives, it is a chemical type of joint.

Regarding the **surface finish of the stone**, any of the finishes in the market are allowed, and the designer's criterion has priority over the rest.

In the case of **slabs with mechanical fixing**, the most common shapes are also square or rectangular, and the sizes allowed are bigger than in the previous case, due to the fact that the mechanical anchors have a higher support capability, as aforementioned.

The fact of choosing a type of anchor is a complicated matter, since different factors take part in it, such as: the type of stone; the slab weight; the wind pressure/suction; the earthquake actions; the environmental actions, such as frost, thermal changes, etc.; the architectural design, or even the price.

1.6.2. Modular tiles

The natural stone small slabs for interior claddings are units obtained by cutting or shearing, with a nominal thickness less than or equal to 12 mm, and, normally, with smaller sizes to that of the slabs.

They are used for interior wall cladding by fixing them in the support by means of mortars or adhesives, as well as the slabs for claddings[2].

[2] Read section 1.6.1.

KEY IDEAS

- Nowadays, the internationalization of the natural stone market permits having an almost unlimited supply of material to successfully resolve any architectural project.
- Natural stone has excellent physical properties with a low maintenance cost.
- The fixing of the stone to the support can be carried out with adhesives or with mechanical means through anchors.

2.

NATURAL STONE CONTROLS

When choosing a stone variety for a certain project it is important to be aware of its characteristics, which can be obtained with a laboratory test.

In case of slabs for facades, the minimum parameters that manufactures must provide project planners are: flexural strength, anchor strength, petrographic study, as well as the value for water absorption at atmospheric pressure.

Based on the results obtained, conditions of use must be defined to establish thickness and setting-up procedures.

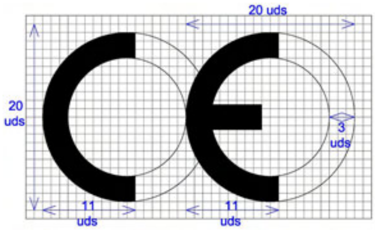
2.1. CE marking

Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products shows the obligatory nature of the CE marking on all products that are permanently used in construction, both in building and civil works, provided that there is a harmonized standard.

CE marking requirements for a construction product are detailed in the **ZA appendix** of each harmonized standard.

The **harmonized European standards** are edited by standardized European organizations and committees according to the Commission's mandate. The aim of its preparation is to achieve a consensus among all interested parties.

The harmonized references standard, compulsories for the purpose of the CE marking, are UNE-EN 1469: Natural Stone Products. Slabs For Cladding. Requirements and UNE-EN 12057. Natural stones. Modular tiles. Requirements.



CE marking for stone products generally requires that the manufacturer performs the following activities that must be subsequently verified by the construction manager:

- Implementation of Factory Production Control (FPC) for manufactured products, following the instructions of the ZA appendix for the application standards to be used in each case.

- Declaration that the product complies with the standard (declaration of compliance), in accordance with the ZA appendix that, in the case of natural stone, is responsibility of the manufacturer (compliance evaluation system 4). The declaration of compliance must include the declarer's name (manufacturing company), the declared product's name (stone variety and specific use), and the reference of compliance with the corresponding harmonized standard.

- Performance of the CE marking by means of an identity label with the product characteristics according to the aforementioned ZA appendix. The CE marking symbol, that must be stamped, will be displayed according to this preference hierarchy: on the product itself (in commercial samples, with a sticker label) on packaging or pallets, on the commercial documentation enclosed (i.e. the delivery note) or even on the manufacturer's website. When supplying, it is recommended that the label is stuck to each pallet.

2.2. Control requirements

Natural stone used in facades must be subjected to the controls showed in the table below:

Table 2.1.: control tests

Controls	Testing standard and remarks
Size requirements	UNE-EN 13373
Flexural strength	UNE-EN 12372 or UNE-EN 13161
Anchor strength	UNE-EN 13364
Water absorption at atmospheric pressure	UNE-EN 13755
Water absorption per capillarity	UNE-EN 1925 (only if the open porosity determined by UNE-EN 1936 is higher than 1 %)
Frost resistance	UNE-EN 12371
Resistance to aging by thermal shock	pr-EN 14066
Sensitivity to changes in appearance produced by thermal cycles	UNE-EN 16140
Marble resistance to thermal and moisture cycles	pr-EN 16306
Resistance to hard objects impact	UNE-EN 14518
Apparent density and open porosity	UNE-EN 1936
Petrographic analysis	UNE-EN 12407
Fire performance	Class A1 (no need of testing)
Soluble salts crystallisation	UNE-EN 12370 (only if the rock's open porosity is higher than 5 %, and in open areas with high pollution levels)
Appearance	UNE-EN 1469

2.2.1. Size requirements

The geometric fixing of the units must be performed according to the UNE-EN 13373 standard. At least, the following **size control checks** must be performed:

Slabs:

- **Thickness:** the table below shows the tolerances allowed according to the UNE-EN 1469 standard:

Nominal thickness e_N (mm)	Tolerances
$12 < e_N \leq 30$	± 10 %
$30 < e_N \leq 80$	± 3 mm
$e_N > 80$	± 5 mm

Table 2.2.: tolerances of slab thickness

- **Length, width, and squaring:** the table below shows the tolerances allowed according to the UNE-EN 1469 standard.

- **Location, depth, and size of anchor drill holes and grooves:** the table below shows the tolerances allowed according to the UNE-EN 1469 standard.

- **Angles and special shapes:** according to the UNE-EN 1469 standard, the piece perimeter must be within the area created by two parallel patterns separated by a ± 1 mm distance from the reference nominal.

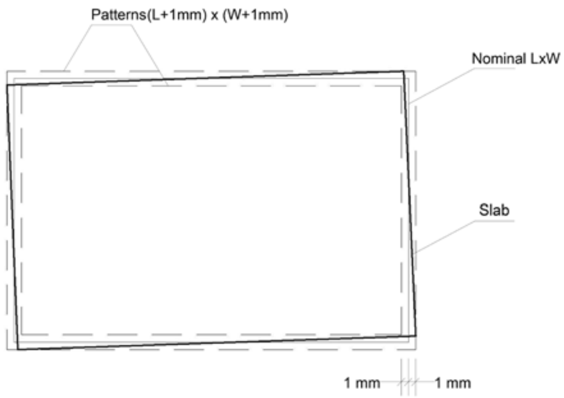


Diagram of patterns to check the size of the pieces

Nominal length and width	< 600 mm	≥ 600 mm
For a thickness ≤ 50 mm with bevelled edges	± 1 mm	± 1,5 mm
For a thickness > 50 mm with bevelled edges	± 2 mm	± 3 mm
Squaring	± 1 mm	± 2 mm

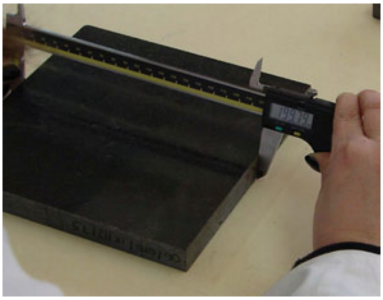
Table 2.3.: tolerances of slab length, width, and squaring

Concepts	Tolerances
Location of the drill hole or groove axis according to the piece's length and width	± 2 mm
Location of the drill hole or groove axis in the edge (from the exposed side)	± 1 mm
Drill hole or groove depth	+ 3/-1 mm
Drill hole or groove diameter	+ 1/-0,5 mm

Table 2.4.: tolerances in location, depth and size of drill holes and grooves

- **Slab flatness requirements:** flatness deviation must not exceed 0.2 % of the piece length, and must be inferior to 3 mm in any case. In the case of stone obtained by shearing, the manufacturer must declare the flatness tolerances.

Size controls in laboratory

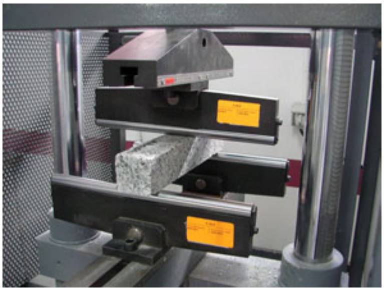


Modular tiles:

- **Sizes, flatness, and squaring:** in accordance with the UNE-EN 12057 standard, the tolerances allowed are those shown in the next table are not valid for plates with exfoliated or broken faces. In these cases, the manufacturer must state the tolerances.

2.2.2. Flexural strength

In order to carry out this control, the material's Lower Expected Value (LEV) of flexural strength has to be determined in megapascals (MPa), according to the UNE-EN 12372 or the UNE-EN 13161 standards. The flexural strength value represents a reference parameter to determine the thickness of the natural stone claddings.



Flexural press

2.2.3. Anchor strength

As a technological test, the LEV of anchor strength (R_a) for bolt anchor fastening will be determined in Newton (N), according to the

Table 2.5.: size and shape tolerances

Property		Size and shape tolerances	
		Non-calibrated small slabs	Non-calibrated small slabs[1]
Sizes	l, b	± 1 mm	± 0.5 mm
	d	± 1 mm	± 0.5 mm
Flatness (only for polished and grinded surfaces)		0.15 %	0.10 %
Squared		0.15 %	0.10 %
[1] The calibrated small slabs indicate a product that has been subjected to a specific mechanical finish to obtain a more precise size. These are the appropriate to be fixed with a fine mortar layer or with adhesives.			

GUÍA PARA EL DISEÑO, CONSTRUCCIÓN Y MANTENIMIENTO DE FACHADAS DE PIEDRA NATURAL

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