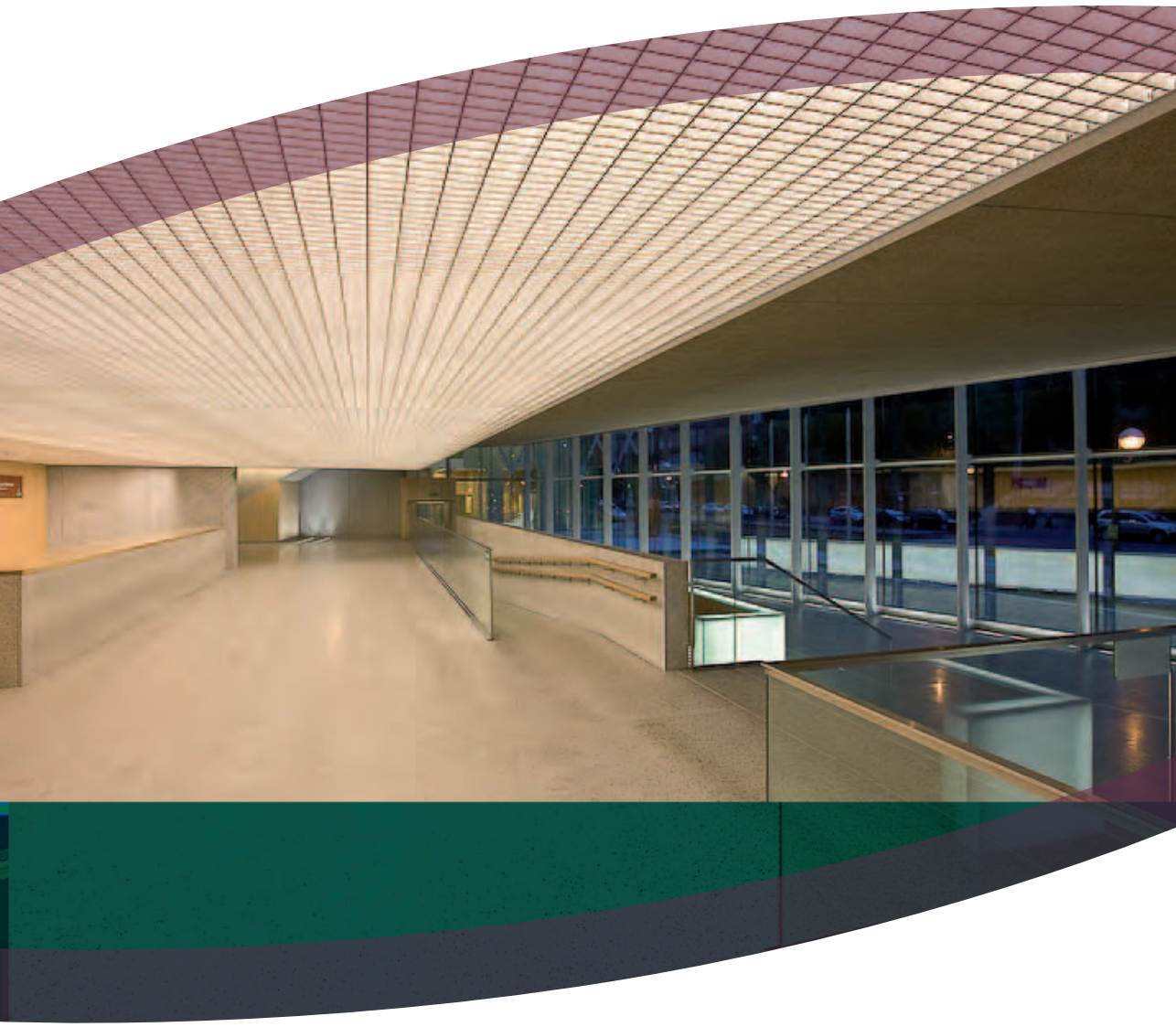
GUIDE FOR THE DESIGN, CONSTRUCTION AND MAINTENANCE OF NATURAL STONE FOR INTERNAL PAVING



CTG
Fundación Centro Tecnolóxico do Granito de Galicia
cluster del granito

Guide for the design, construction and maintenance of natural stone for internal paving

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GUIDE FOR THE DESIGN, CONSTRUCTION AND MAINTENANCE OF NATURAL STONE FOR INTERNAL PAVING.

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PRESENTATION

This technical guide about pavements introduces the reader to the world of natural stone, explaining the countless advantages this material offers in terms of design and construction, as well as the requirements that must be met to optimize its use.

The requirements demanded from the materials that make up the pavement system as a whole, the section calculation tools, the requirements for receipt acceptance at worksite, as well as the quality controls on the finished work units are described in it.

The final chapters offer the reader a classification of the most common damages affecting the stone flooring and the repairs that have to be done to correct them. This way, the opportunity of preventing the damages on stone flooring is offered by means of the prior analysis of the interacting actions.

In addition, it provides a compendium of recommendations regarding pavement conservation and maintenance and an analysis of cleaning techniques. This section underpins the importance of proper maintenance and cleaning throughout the pavement lifespan in order to get the most from the qualities offered by this material.

José Ángel Lorenzo Ramírez
FCTGG Manager

INTRODUCTION

The use of stone for pavement construction has been practiced by man throughout time with satisfactory results.

Today, the wide range of materials offered by the sector go beyond the natural stone products typical of the region opening the market to new varieties from anywhere in the world, wherever they may come from, as long as they can offer new features to the ones we already known.

With regard to granite, the entire value chain is concentrated in Galicia. Therefore this is a strategic sector for a region with an important concentration of natural resources, a significant extractive and productive industry and the necessary technology and know-how to provide a quality product to the end customer.

Galicia is the undeniable leader in raw granite production in Spain. Each year, around 800 000 granite blocks are extracted from Galician quarries, equivalent 92% of the national total. In addition, the region is leader in granite transformation in Spain. The eleven million square meters of products manufactured in Galicia annually accounts for 78 % of the total production in Spain.

The outstanding quality of its raw material and a state-of-the-art transformation industry stands the region at the second most important in Europe and the fourth in the world. This has led to international recognition resulting in important financial, social and technological changes for Spanish producers.

One of the most significant factors on the industries development is associated to architectural design as it prompted the emergence of different varieties of granite, enabling prescribers to find solutions to any architectural idea they may need to develop.

Therefore, granite varieties used for construction continue to grow with new surface finishes, greater formats and advanced quality controls at production quality controls.

1.

STONE FOR INTERNAL PAVING 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 use of stone for internal paving construction dates back to far-off times, before the Christian age.

It is interesting to notice the human being's persistence in using stone as paving material, without almost manufacturing the raw material, as it is in nature, regardless the technological changes the construction industry has experienced throughout the centuries. This gives a clear proof that it has excellent durability features.

Today, it is difficult to find ancient pavements preserved so well like the flooring made of stone in cathedrals, palaces, and many other types of buildings, where the passing of time did not make them loose their aesthetical and functional features.

In a historic overview, it is inevitable to talk about the Roman mosaics as an artistic and exceptional pavement model, which still prevails nowadays.

This type of pavement was made up of small pieces or tesserae of different kinds, but mainly of calcareous stones, such as compact limestone or marble.

The constructive system was based on a previously prepared floor and was made up of a mortar of lime and sand or tile dust, to obtain a reddish colour, a granular layer made

Ancient flooring designs. Right, Roman recently constructed mosaic in an assembly stage.

up of tile fragments, and a final layer of lime and sand mortar for the adherence of the mosaic tesserae.

This constructive typology, as well as the one of Roman roads, essentially matches the ones used in nowadays pavements.

1.2. Natural stone designation

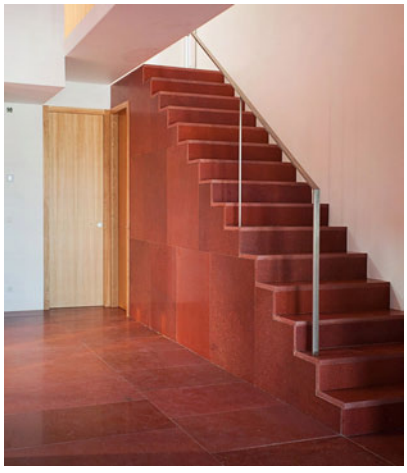
According to European regulations, in any pavement project, stone should be classified right from the outset from two points of view: a scientific or petrographic classification and a commercial designation or classification.

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 the establishment of prior evaluation criteria on rock behaviour 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, subject of good polishing. It has a good level of flexural and compression resistance and, to a lesser degree, to erosion caused by abrasion.
- **Limestone:** a sedimentary rock made of calcite carbonate crystals but less crystalline than marble There are frequent bioclastic varieties with many fossilized shell remains.
- **Sandstone:** a sedimentary rock made of quartz sand, feldspar, etc. bound together by variable composition cement.

Internal paving of natural stone slabs and stairs



- **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 are at risk of shearing.

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 their design needs.

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.

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 for interiors

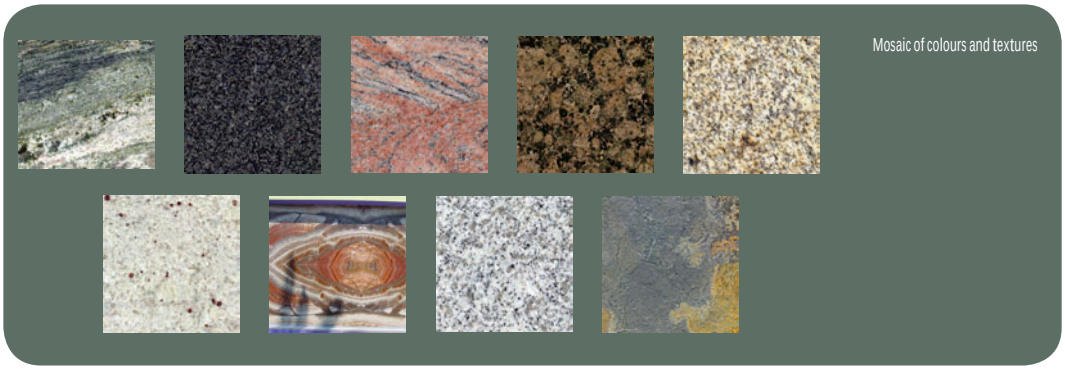
The surface finish of the stone constitutes constitutes its paving coat and represents its hallmark, along with size and petrographic varieties.

Surface finishes are always undergoing new developments but these are the most important ones:

- **Polished:** a finish which final appearance is achieved through solutions, waxes, etc.; and offers a mirror like shine appearance. This type of finish must be used with caution in internal-pavements with liquid spillage risk for safety reasons against slippage.

- **Honed:** finish achieved with variable granulometric grinding wheels which gives a smooth surface with a somewhat matt appearance. A study is needed in each case in order to assess the slipping risk.

- **Bush hammered:** a finish achieved with variable geometry bush hammers or spiked wheels that bang the stone surface, giving it a rough surface. Bush hammered surfaces are safe against slipping.



Mosaic of colours and textures

- **Flamed:** achieved by thermal lance, which gives a rough finish. It is safe against slipping.

- **Split:** it is achieved by cutting up with a shearing machine, which gives a very rough finish, which is safe against slipping.

- **Sheared:** it is a natural stone shearing given by sedimentation or schistosity planes.

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

- **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, which can involve some slipping risk.

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

- **Slotted:** achieved by making slot drawings on the visible surface. It is used to identify the presence of, i.e., a ramp or stair section for accessibility reasons.

Most important surface finishes

Polished

Honed

Bush hammered

Flamed

Split

Sheared

Brushed

Sand blasted

Sawn

Slotted

1.5. Advantages of stone for pavement construction

Pavements constructed with natural stone for using in interiors has many advantages compared to other competing products. Three features make the use of this material inviting: beauty, durability and design possibilities.

These three features are due to its properties, leading to a number of **advantages,** some of which are cited below:

- **Excellent physical properties:** the high level of resistance to stone compression, in particular granite, makes it an extremely strong and consistent construction material. The same can be said about abrasion resistance, which is a priority in terms of the durability for a pavement subject to an intense pedestrian traffic.

- **Non-flammable:** natural stone has an A1 Class rating for its fire performance, classifying 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 it was first 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 not only affect the aesthetic result of the pavement, but also improve certain technological features such as slippiness.

- **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:** among all the materials used for paving, stone is the one that can offer the greatest formats.

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

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

- **Sustainability:** stone manufacture clearly requires less energy consumption than many other materials such as ceramic or concrete pavements. The fact that stone is a natural product already makes it easier to extract and involves much simpler manufacturing processes.

Reduction in energy demand

Experts estimate that buildings consume up to 50 % of the energy available for the user. In this regard, unlike other materials used for pavement coating, 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.

Granite block cut with disc

The following table 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.

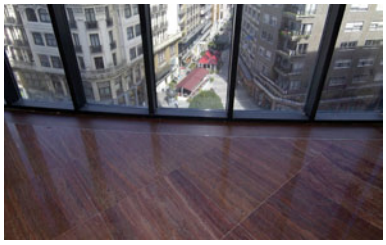
Material	Embodied energy (kWh/t)
Steel	7 000
Aluminium	28 000
Copper	8 000
Wood	1 000
Glass	2 000
Granite	780

Table 1.1.: embodied energy in construction materials

1.6. Formats used in interior flooring

Natural stone for internal paving are made up of slabs or modular tiles, as defined in the European standards UNE EN 12058 and UNE EN 12057, respectively.

There are other complementary natural stone units in addition to these, such as baseboards, trims, treads and risers, which are also part of the flooring.



1.6.1. Slabs for floors

They are used for paving interior spaces with pedestrian traffic or, in really specific cases such as factories, warehouses, etc., for paving spaces with light vehicle traffic.

*Natural stone **slabs** are paving units obtained by cutting or shearing, which nominal thickness is over 12 mm, and its width is more than twice its thickness. These are laid on a structure by means of mortars, adhesives, and other support elements. In the case of stairs, the riser thickness can have a minimum thickness of 10 mm, providing that its stability is guaranteed.*

Slabs with less thickness can be used in the case of restricted use pavements, providing that they resist the traffic load they are going to undergo.

Furthermore, stone slabs are characterized by the type of stone selected, by its size at ground level, its thickness, its shape, and its surface finish.

Regarding size, the commercial catalogues of these products contain a really wide format offer, with a clear trend towards bigger and bigger sizes.

The shape of paving units is mainly rectangular; even though, nowadays, technology allows the development of curved cuts, obtaining very attractive and new designs.

Regarding slabs surface finishes, these have a double function: offering different visual appearances of the pavement, which enriches the design possibilities, and obtaining the security parameters against slipping needed for every application. The most used finishes in internal paving are those which show a smooth appearance, such as polished or honed.

1.6.2. Modular tiles for floors

Natural stone modular tiles are paving units obtained by cutting or shearing, which nominal thickness is lower than 12 mm, and its width is more than twice its thickness. These are laid on a structure by means of mortars, adhesives, and other support elements.

Due to their small thickness, modular tiles are mainly used in single-family houses to pave spaces with a small pedestrian traffic, such as bathrooms, dressing rooms, etc.[1]

Square or rectangular shaped formats are normally used, and their most common sizes are 20x10, 20x20, or 30x30.

[1] For more intense pedestrian traffic, it is recommended to use slabs, as defined in section 1.6.1.

1.6.3. Trims, skirting boards, treads and risers

Trims are flat pieces of natural stone obtained by cutting or shearing, which nominal thickness is over 10 mm. They are placed on the walls adjacent to the stairs. Their function is to protect the face they are supported on, as well as to hide the joint where flooring and wall meet. See 1

Skirting boards are flat pieces of natural stone obtained by cutting or shearing, which nominal thickness is over 10 mm. They are placed on the walls at both sides of the pavement. It has the same function as trims. See 2

They show rectangular shapes, and the most common sizes are between 8 and 20 mm high.

The **tread** (horizontal section 3) and the **rise** (vertical section 4) are used for covering the stairs. They are flat pieces of natural stone obtained by cutting or shearing, which nominal thickness is over 12 mm in the case of treads, and 10 mm in the case of rises, providing that their stability is guaranteed.

They show rectangular shapes with the same sizes as those of the stairs they are meant to cover.

KEY IDEAS

- Stone durability in internal paving is an unquestionable fact, as the numerous architectural remains constructed with this material show.
- Colour, texture and finish variations make every single stone unique. Nowadays, there are countless stone varieties for developing paving projects. Surface finishes provide the pavement different visual appearances. Furthermore, they allow obtaining the security parameters against slipping requested by the regulations in force.
- The good mechanical performance of the stone and its excellent abrasion resistance make it an ideal material for constructing interior flooring.
- The stone manufacturing process needs less energy consumption than many other materials.
- Internal paving is made up of slabs or paving modular tiles, as well as other units such as trims, skirting boards, treads, risers, etc.

2.

NATURAL STONE CONTROLS

When choosing a stone variety for a certain project you must be aware of its characteristics, which can be obtained with a laboratory test.

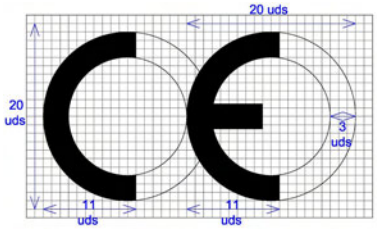
*In the particular case of internal paving, the **minimum** parameters that manufactures must provide project planners are: flexural strength, skid resistance, as well as the value for water absorption at atmospheric pressure.*

Based on the results obtained, conditions of use must be defined to establish thickness and placement 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 obliges manufacturers to implement CE marking on all products that are permanently used in construction both in building and civil works, only when a harmonized standard exists.

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.

Detailed below is a list of the harmonized European standards which must be complied with according to each product family:

Table 2.1.: harmonized standards for internal paving

European Committee for Standardization	Reference	Standard title	Date the CE marking came into force
CEN/TC 246	UNE-EN 12058:2005	Natural stone products. Slabs for floors and stairs. Requirements	1/9/2006
	UNE-EN 12057:2005	Natural stone products. Modular tiles. Requirements	1/9/2006

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 identifying 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: for 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. Product requirements and control checks

The **natural stone** used for internal paving must be object of the **requirements and controls** shown in the table below:

Table 2.2.: product requirements and control checks

Controls	Slabs or modular tiles	Testing standard and remarks
Size and surface finish requirements	X	UNE EN 12058 (slabs) and UNE EN 12057 (modular tiles)
Flexural strength	X	UNE-EN 12372 or UNE-EN 13161
Adherence resistance	X	See chapter 2.2.4.
Water absorption at atmospheric pressure	X	UNE-EN 13755
Water absorption per capillarity	X	UNE-EN 1925 (only if the open porosity determined by UNE-EN 1936 is higher than 1%)
Resistance to erosion by abrasion	X	UNE-EN 14157
Skid resistance	X	UNE-EN 14231 o UNE-ENV 12633
Bulk density and open porosity	X	UNE-EN 1936
Resistance to thermal shock	X	pr-EN 14066 (only in that areas where slabs are expected to be subject to important thermal cycles)
Sensitivity to changes in appearance produced by thermal cycles	X	UNE-EN 16140
Resistance to hard objects impact	X	UNE-EN 14158
Petrographic analysis	X	UNE-EN 12407
Fire performance	X	Class A1 (no need of testing)
Appearance	X	UNE-EN 12057 (modular tiles) and UNE-EN 12058 (slabs)

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 12058 standard.

Nominal thickness e_N (mm)	Tolerance
$12 < e_N \leq 15$	± 1,5 mm
$15 < e_N \leq 30$	± 10 %
$30 < e_N \leq 80$	± 3 mm
$e_N > 80$	± 5 mm

Table 2.3.: nominal thickness requirements

It must be considered that more strict tolerances can be required when the laying is done with adhesives in a thin layer. Furthermore, these tolerances cannot be applied in sheared or split materials, in which case the thickness can be stated as a range of value and their tolerance, for example: 50-60 mm ± 6 mm.

  - **Length and width:** the table below shows the tolerances allowed according to the UNE-EN 12058 standard.

If the manufacturer wishes so, it is also possible to specify more strict tolerances.

Size controls in laboratory

  - **Face flatness:** flatness deviation in the surface must not exceed 0.2 % of the floor tile length, and must be lower than 3 mm. These tolerances are not applicable in the case of sheared or split faces, and the manufacturer is the one who must specify them.

  - **Angles and special shapes:** the tolerance allowed at any point will be the one specified in table 2.4. According to the UNE-EN 12058 standard, the piece perimeter must be within the area created by two parallel patterns separated by a distance equal to the allowed tolerance.

Diagram of patterns to check the shape and squaring of the pieces

Nominal length and width in mm	< 600 mm	≥ 600 mm
Bevelled edges thickness ≤ 50 mm	± 1 mm	± 1.5 mm
Bevelled edges thickness > 50 mm	± 2 mm	± 3 mm

Table 2.4.: length and width requirements

- **Modular tiles:**

  - **Sizes, flatness and squaring:** according to the UNE-EN 12057 standard, the tolerances shown in the table below are not valid for modular tiles with exfoliated or split faces. The manufacturer must specify the tolerances in these cases.

Table 2.5.: size and shape tolerances

Properties		Tolerances	
		Non calibrated modular tiles	Calibrated modular tiles [1]
Sizes: length (l), width (b) and thickness (d)	l, b	± 1 mm	± 0.5 mm
	d	± 1.5 mm	± 0.5 mm
Flatness (only for polished and ground surfaces)		0.15 %	0.10 %
Squaring		0.15 %	0.10 %

[1] The calibrated modular tiles 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.

2.2.2. Surface finish

The surface finish in slabs or modular tiles must show a uniform aspect.

The surface finish of some stones needs the addition of resins, fillers, or other products for filling hollows, discontinuities, etc., which is considered a normal stage of the finish process. In these cases, the manufacturer must specify the features of these filling materials, as well as the type of treatment.

2.2.3. Flexural strength

It must determine the material's Lower Expected Value (LEV) of flexural strength, according to UNE-EN 12372 and UNE-EN 13161 Standards.

Flexural strength test

The flexural strength value is the reference parameter used to determine the thickness of slabs.

2.2.4. Adherence resistance

The person who sets up the pavement is responsible for knowing the adherence resistance value, and must take the national laying standards into account. The adherence value depends on the laying conditions, the type of mortar or adhesive, and for a specific stone, the type of backfilling finish.

2.2.5. Water absorption at atmospheric pressure

Water absorption at atmospheric pressure is determined according to the UNE-EN 13755 standard. This parameter is very important in quality control tasks.

2.2.6. Water absorption by capillarity

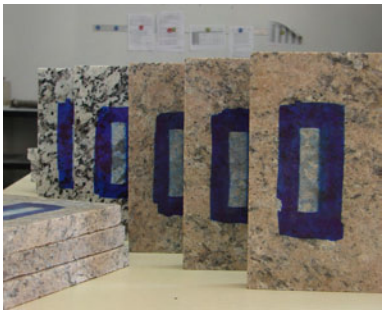
The capillarity coefficient value must be determined in accordance with the UNE-EN 1925 standard if the client requests it, providing that the open porosity of the rock is higher than 1 % according to the UNE-EN 1936 standard.

In general, the capillarity coefficient must be lower than 4 $g/m^2.s^{0.5}$. Values greater than this generally require a detailed study justifying the conditions for its use.

2.2.7. Erosion resistance

By means of this test, the average value of the resistance to erosion by abrasion and the Highest Value Expected (HVE) are determined according to the process described in the UNE-EN 14157 standard.

The result of this test is the measure of the width of the mark left by a disc on the stone, at a specific number of revolutions in a specific time.



Marks of erosion by abrasion in the abrasion test

Acceptable maximum values recommended for abrasion resistance are indicated in the following table:

Restricted spaces	Common spaces	Industrial spaces and light traffic areas	Industrial spaces, fast traffic and stairs
30 mm	27 mm	23 mm	20 mm

Table 2.6.: acceptable maximum values for erosion resistance

Accepting a stone with an erosion higher than the specified in the table means accepting the following premises:

- Higher pavement abrasion may be compensated with greater slab thickness in order to maintain the resistant section throughout its useful life.

- The discomfort of cleaning the slumping of solid materials due to excessive abrasion from a cleaning point of view.

2.2.8. Skid resistance

This test is carried out using paving units for each type of surface finish in each case.

When carrying out site control tasks, if different pavement unit types simultaneously correspond because are made with the same type of stone and with identical surface finish, skid testing can be performed on one of the stones as long as this is authorized by the project management.

Skid resistance is determined using the friction pendulum and evaluated in Skid Resistance Value (SRV) units, according to UNE-EN 14231 and UNE-ENV 12633 standards. In the case of internal paving, the test will be carried out in both dry and wet conditions, depending on whether there is any liquid spilling risk or not.

Friction pendulum

The requirements for skid resistance will be those laid down in every case by the Technical Building Code (CTE) when applicable.

In that sense, it must be considered that the CTE requirements are only applicable to building worksites, the floors of buildings or areas used with purposes such as public residential, public health, educational, commercial, administrative and public audience. The private use areas are left out of its scope.

For pavements not included in CTE, the skid requirements are those that appear in the UNE 22202-1 standard. Constructing of pavements with natural stone. Part 1: Slabs for paving floors and stairs.

2.2.9. Bulk density and open porosity determination

The manufacturer must declare the bulk density and the open porosity according to the procedure described in the UNE-EN 1936 standard.