Contract no.: NMP2-CT-2005-515762

I-STONE

Re-engineering of natural stone production chain through knowledge based processes, eco-innovation and new organisational paradigms

Deliverable 5.28 Handbook for proper selection of stone to each application and climate - Rev 1

October 2008

Enclosures

Partners contributing to the work of this deliverable:

BBRI has been the lead contractor of subtask 5.1.1: *Development of an expert system (handbook) for evaluation of durability and specification criteria*

The subtask has engaged the following partners: BBRI, SP, BGC, MoG and PCG. The role of each partner is described in the Final report of task 5.1 and partly in this report

1. Introduction

This handbook is mainly directed to architects, building designers, experts and contractors who are likely to use natural stone in their projects.

It has been written in order to give the reader a concise and practical information about the basic characteristics of the material “natural stone”, and to propose suitable “tools” that will facilitate a proper selection of the stone type in function of its final use. Only a choice made in full knowledge of the basic characteristics of the material, of its performance and durability against the foreseen solicitations will ensure the necessary quality of the stone work and thereby a possibility to reach its intended service life.

The current European standards are systematically referred to in these guidelines as they constitute the first technical reference documents to be used while prescribing natural stone, but they are here always completed and commented in order to give the reader the necessary information to understand and use them correctly.

The knowledge which made it possible to write down this handbook results mainly from the I-STONE project (Re-engineering of natural stone production chain through knowledge based processes, eco-innovation and new organisational paradigms - contract no.: NMP2-CT-2005-515762) and in particular from WP 5.1 which concerns “Quality Assurance”.

2. Climatic influences on stone elements in buildings

2.1. General European climate

Europe has a variety of climates, but most of the continent has a mild weather. The following map and legend show what the climate is like throughout the continent. Note that it is greatly simplified.

Figure 1: The different climates in Europe

Europe generally has milder weather than parts of Asia and North America at the same latitude. For example, Berlin (Germany), Calgary (Canada), and Irkutsk (in the Asian part of Russia), lie at about the same latitude. But January temperatures in Berlin average about 8 degrees C higher than those in Calgary, and they are almost 22 degrees C higher than the average temperatures in Irkutsk.

Europe's mild climate is caused by winds that blow across the continent from the Atlantic Ocean. The winds are warmed by the Gulf Stream, a powerful ocean current that carries warm water from the Gulf of Mexico to the western coast of Europe. The winds influence most of the continent because no mountain barrier is large enough to block them and because much of Europe is located within 480 kilometres of the Atlantic Ocean.

The most spectacular effect of the Gulf Stream and the strong westerly winds on Europe occurs along the Norwegian coast. Much of Norway's coast lies in the Arctic region, most of which is covered with ice and snow in winter. But almost all of Norway's coast - even the part in the Arctic region - remains free of ice and snow throughout the winter.

In general, northern Europe has longer, colder winters and shorter, cooler summers than southern Europe. In addition, winters are longer and colder and summers shorter and hotter in the east than in the west. Glasgow, Scotland, for example, has an average temperature of 3 degrees C in January. But Moscow, which lies at the same latitude, has an average January temperature of -10 degrees C.

Most of Europe receives from 50 to 150 centimetres of precipitation each year. The greatest annual precipitation--usually more than 200 centimetres--occurs in areas just west of mountain ranges. Such regions include parts of western Britain and western Norway. The continent's lightest annual precipitation - usually less than 50 centimetres - occurs in three general areas: (1) east of high mountain range, (2) far inland from the Atlantic Ocean, and (3) along the Arctic coast. Such regions include central and south-eastern Spain, northern Scandinavia, northern and south-eastern parts of European Russia, and western Kazakhstan.

2.1.1 EOTA climate classification

The general description of the European climate given above is the most conventional classification, but other ones exist.
In this handbook we will use the EOTA classification (European Organisation for Technical Approvals) in order to assess the working life of building materials. This climate classification comes from a building context. In the frame of the assessment of working life of building products, the EOTA has produced a simple sub-division of Europe into three temperature zones based upon general climatic conditions. This classification is given in the following *table 1*.

Table 1: EOTA-classification

Zone	Winter Conditions (DEC, JAN, FEB)	Summer Conditions (JUN, JUL, AUG)
A	Cold winters. Several months temperature rarely above 0°C. Average daily temperature below 0°C. Min temperatures may be below -30°C.	Max temperature rarely above 30°C.
B	Moderate winters. Frequent frosts. Average daily temperature 0 to 5°C. Min temperatures may be below -20°C.	Max temperature occasionally above 30°C.
C	Warm winters. Infrequent frosts. Average daily temperature above 5°C	Max temperature frequently above 30°C. Occasionally above 40°C.
Mountainous regions above 1000 m	Zone A conditions.	Zone C or B conditions.

2.2 Weathering and erosion

Solid as the hardest rocks may seem, they eventually weaken and crumble when they are exposed to water and the gases and pollution of the atmosphere. However rocks may take thousands of years to disintegrate. Weathering is the general process by which rocks are broken down at Earth's surface. It takes place in two ways:

- Chemical weathering occurs when the minerals in a rock are chemically altered or dissolved. The blurring or disappearance of lettering on old gravestones and monuments is attributable mainly to chemical weathering.
- Physical weathering occurs when solid rock becomes fragmented by physical processes that do not change its chemical composition. The rubble of broken stone blocks and columns that were once stately temples in ancient Greece and the cracks and breaks in the ancient tombs and monuments of Egypt are primarily the result of physical weathering.

Chemical and physical weathering interact and reinforce each other. The faster the decay, the weaker the pieces and the more susceptible to breakage. The smaller the pieces, the greater the surface area available for chemical attack and the faster the decay.

Erosion on the other hand moves the weathered material, carry it away and deposit it somewhere else. And as erosion carries away weathered solid material, it exposes fresh, unaltered rock to weathering.

2.2.1 The factors that control weathering

All rocks weather, but the manner and rate of their weathering vary. The three key factors that control the fragmentation and decay of rocks in buildings are the properties of the natural stone, the climate and the length of time they are exposed to atmospheric conditions.

2.2.1.1 Properties of the natural stone

The nature of a natural stone affects weathering because:

- different minerals weather at different rates and,
- the structure of natural stones affects their susceptibility to cracking and fragmentation

When for example the inscriptions of tombstone of limestone and granite are compared after a couple of hundred years, a big difference can be observed. The limestone's surface will be dull and the letters inscribed on it will look like they have melted away. Granite will show only minor changes. The difference in the weathering of granite and limestone reflect the different solubility of their constituent minerals in water; i.e. the extent to which they can dissolve in water. Given enough time, however, even a resistant rock will ultimately decay/Looking more closely at the weathered granite, perhaps with a hand lens, different patterns of weathering in its various mineral grains. The feldspar crystals would show signs of corrosion, and their surfaces would be chalky and covered with a thin layer of soft clay. The outer layers of the grains of feldspar will have undergone a change in chemical composition and turned into a new mineral. The quartz crystals will appear fresh - clear and unaltered.

The internal structure of natural stones also affects physical weathering. Granite constructions may remain unbroken and uncracked even after centuries, though they may show evidence of superficial chemical weathering. The granitic massive elements may have no planes of weakness that contribute to cracking or fragmentation. In contrast, shale, a sedimentary rock that splits easily across thin bedding planes, breaks into small pieces so quickly that only a few years after placing, the stone will turn into sand and gravel.

Figure 2: Weathering of a porous limestone

2.2.2.2 Climate: rainfall and temperature

Looking at buildings all over the world reveals that the rate of weathering - chemical and physical - varies not only with the properties of the natural stone itself but also with the climate - the amount of rainfall and temperature.

Old stone constructions in a hot, humid area may be badly chemically weathered, whereas those of the same age in an equally hot but arid region are hardly touched. And buildings in cold, dry arctic regions show even less chemical weathering than those found in the hot, arid area. Climate exerts strong control over the rate of chemical weathering. High temperatures and heavy rainfall speed up the chemical weathering; cold and dryness impede the process. In cold climates, water may be chemically inert because it is frozen. In arid regions water is relatively unavailable. In both cases, chemical weathering proceeds slowly. In climates in which chemical weathering is minimal, physical weathering may be active. Freezing water may act as a wedge, widening cracks and pushing the stone pieces apart.

2.2.2.3 Length of exposure

The longer a stone weathers, the greater its alteration, dissolution and physical breakup. Stone elements that have been exposed to the climate for many hundred of years form a rind - an external layer of weathered material several millimetres thick which surrounds the fresh, unaltered rock.

Table 2: Major factors controlling rates of chemical weathering

	CHEMICAL WEATHERING RATE		
	SLOW ←	→	FAST
properties of natural stone			
mineral solubility	low (e.g. quartz)	moderate (e.g. pyroxene, feldspar)	high (e.g. calcite)
stone structure	massive	some zones of weakness	very fractured or thinly bedded
climate			
rainfall	low	moderate	heavy
temperature	cold	temperate	hot
length of exposure	short	moderate	long

2.3 What determines the durability of stone elements?

The durability of stone elements can be influenced by a variety of factors, including stress along natural zones of weakness and biological and chemical activity.

2.3.1 Natural zones of weakness

Most stones have natural zones/planes of weakness along which they tend to crack. In sedimentary rocks such as sandstone and shale, these zones are the stratification planes formed by the successive layers of solidified sediments. Metamorphic rocks such as slate form parallel planes of fractures that enable them to be split easily to form roofing tiles. Granites and other rocks are massive - that is, large masses that show no changes in rock type or structure. Massive rocks tend to crack along regular fractures at intervals of one to several meters called joints. These and more irregular fractures form while rocks are still deeply buried in Earth’s crust. Through uplift and erosion, the rocks rise gradually to the surface. There, freed from the weight of tons of overlying rock, the fractures open slightly. Once the fractures open a little, both chemical and physical weathering work to widen them.

2.3.2 Activity by organisms

Both chemical and physical weathering are influenced by the activity of organisms, from bacteria to tree roots, all working in ways that destroy the rock. Bacteria and algae invade cracks. The acidity these organisms produce then promotes chemical weathering. When a tree (or plant) took root in a stone element, it causes a crack that has been widened. The physical force of the growing root system helps pry cracks apart.

2.3.3 Frost action

A stone element can break up into pieces as result of the expansion of freezing water. As the water freezes, it exerts an outward force strong enough to break up the stone matrix and introduce more cracks.

The most important parameter regarding the stone characteristics is the porosity that has an influence on the frost resistance of the stone. The porosity of a porous medium (such as stone or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by the ratio:

$$\phi = \frac{V_V}{V_T}$$

where V_V is the volume of void-space (such as fluids) and V_T is the total or bulk volume of material, including the solid and void components.

Porosity depends on the size and shape of the grains and how they are packed together. The more loosely packed the grains, the greater the pore space between the grains will be. Consolidated rocks (e.g. sandstone, shale, granite or limestone) potentially have more complex "dual" porosities, as compared with sediment. The rock itself may have a certain (low) porosity, and the fractures (cracks and joints), or dissolution features may create a second (higher) porosity. The interaction of these porosities is very complex.

In order to correlate climatic parameters to real stresses induced by frost, we can define, for a given type of stone used in a given application, a **critical climatic event** (CCE) as a frost period preceded by a certain quantity of rain, which is likely to affect the durability of the exposed material when repeated.
More precisely:

- the frost period should be such that all water present in the pores of the stone will freeze. That means that the minimal temperature will drop below a critical temperature (T_{ci}) during a sufficient period of time and
- the quantity of rain preceding this frost period should be such that the water content of the stone will be higher than a critical water content (S_{ci}).

T_{ci} and S_{ci} are characteristic for each type of stone and have to be determined experimentally in laboratory conditions. Given the results of a number of tested stone types, we can state that the maximum temperature at which water in a stone will freeze is -2 °C and for climate type B the water content can be seen as constant during the winter.

For each EOTA climate type, the number of frost cycles are established as is given in the following table:

Table 3: Climate type in function of the number of frost cycles (paving applications as reference)

EOTA climate type	number of cycles with air temperature < -2 °C	number of cycles with temperature in stone < -2 °C
A - severe	> 40	> 20
B - moderate	20 - 40	10 - 20
C - light	< 20	< 10

It is important to note that the climate classifications do not take the CCE into account. In order to develop a climate classification for stone applications we also need to consider precipitation in combination with the freeze-thaw cycles!

2.3.4 Mineral crystallization

When minerals crystallize from solutions in stone fractures or the porous matrix, it generates an expansive force that can split the stone element. This phenomenon is most common in arid regions, where dissolved substances derived from chemical weathering may crystallize as a solution evaporates. The minerals are commonly calcium carbonate (calcite), occasionally gypsum and rarely rock salts (more common when used in combination with mortar and/or bricks).

2.3.5 Alternating heat and cold

Stone elements can be weakened or even break as a result of daily alternation between hot days and cold nights (or rainfalls). Part of the breakage process may be weakening of the stone caused by its expansion in the heat and contraction during the cold.
When thin natural stone slabs are placed on a façade with a NE-SW direction, the temperature measured on the elements surface of a dark stone can reach 80 °C on a sunny day. A sudden thunderstorm or the nightfall can make the temperature drop by 60 °C or more.

3. Introduction to rock types and their formation

3.1 Rock formation

The term “rock” indicates any material of the earth's crust that - normally distributed on a large scale – is formed by a constant mixture of minerals. The same rock can be composed of one or more different minerals.

The earth, at the beginning, a gaseous and then a liquid spheroid, obtained by cooling a slaggy surface, which led to the creation of the *magmatic or igneous rocks*. By the condensation of the water, these rocks were exposed to chemical and mechanical weathering, so they were destroyed and by which components of the first *sedimentary rocks* were formed. Glaciation-deglaciation is another major contributor to sediments.

Under the influence of various factors such as temperature and pressure, sedimentary and igneous rocks can be turn into *metamorphic rocks*. This is done mainly by re-crystallization.

So, rocks can be classified into three groups: igneous rocks, metamorphic rocks and sedimentary rocks.

The schedule of Figure 3 gives a brief presentation of the three major rock types, along with the processes that led to the formation of them. This chart shows the cyclical nature of this process.

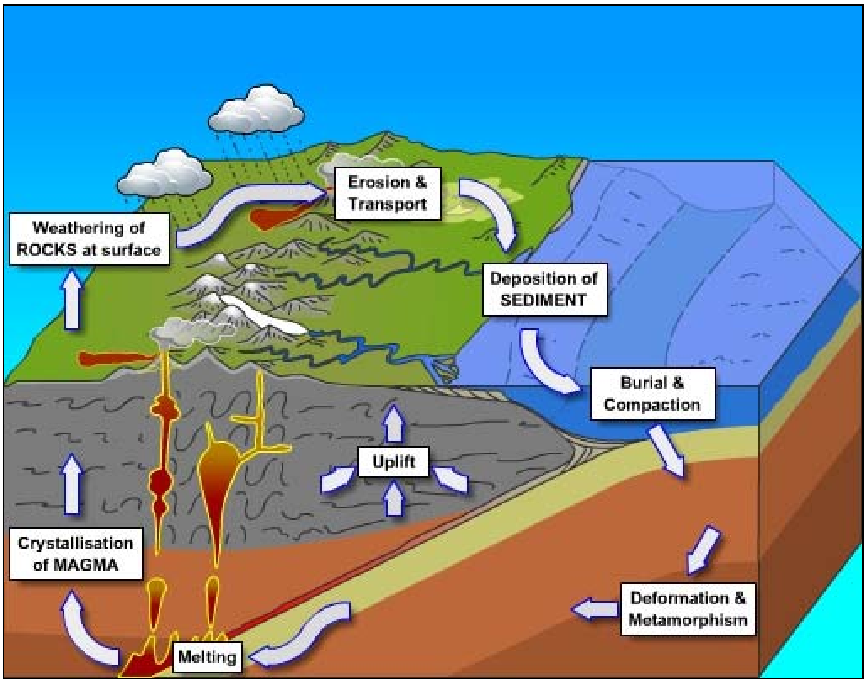


Figure 3: Rock cycle

3.2 Stone classification

All the stones present on and in the Earth's crust can be classified into three general groups but within these a variety of different stone types can be found. There exists a European standard (EN 12670) that contains all the geological diagrams with the parameters to define a certain stone type. This chapter will only give an overview of the most common stone types with their geological characteristics.

3.2.1 Magmatic rocks

The classification of magmatic rocks is based upon the texture and the chemical (mineral) composition. The texture of magmatic rock is influenced by the time that the minerals get to crystallize.

When magma spreads out on the earth surface, the crystallization time is very short because the very hot magma enters suddenly an environment of 10 - 30 °C which cools down the magma very quickly. The minerals don't get much time to crystallize and the resulting rock type consists of very small crystals. These rocks are called *extrusive or volcanic rocks*.

Magma that cools down within the earth has large crystals. Because the cooling is very slow the minerals have the time to grow. These kinds of stones are called *plutonic or intrusive igneous rocks*.

The second classification factor is the chemical composition. The content of the silica is the most important. A magmatic rock with a high content of silica is called felsic (from feldspar and silica) and one with a low content is called mafic (from magnesium and ferric, from Latin ferrum, iron). Mafic minerals crystallize at higher temperatures - that is, earlier in the cooling of a magma - than those at which felsic minerals form. Felsic rocks and minerals tend to be light in colour. Mafic rocks on the other hand are high in dark coloured minerals. The common minerals that are found in igneous rocks are:

Table 4: Mineral composition of felsic or mafic igneous rocks

felsic		**mafic**	
quartz	SiO_2	biotite (mica)	$(K,Mg,Fe,Al)Si_3O_{10}(OH)_2$
potassium feldspar	$KAlSi_3O_8$	amphibole group	$(Mg,Fe,Ca,Na)Si_8O_{22}(OH)_2$
plagioclase feldspar	$NaAlSi_3O_8$ - $CaAl_2Si_2O_8$	pyroxene group	$(Mg,Fe,Ca,Al)SiO_3$
muscovite (mica)	$KAl_3Si_3O_{10}(OH)_2$	olivine	$(Mg,Fe)_2SiO_4$

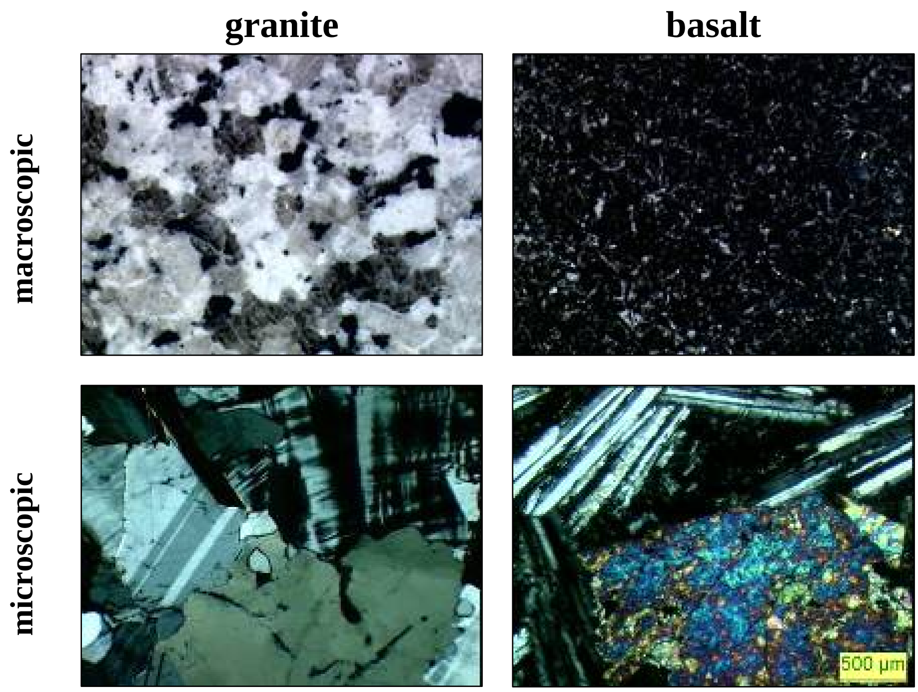
Some extrusive and intrusive igneous rocks are identical in composition and differ only in texture. Basalt, for example, is an extrusive rock formed from lava. Gabbro has exactly the same mineral composition as basalt but is formed deep in the Earth's crust. Similarly, rhyolite and granite are identical in composition but with different textures. Thus, extrusive and intrusive rock form two chemically and mineralogically parallel sets of igneous rock.

Table 5: Types of igneous rocks

COMPOSITION	Intrusive		Extrusive
felsic	granite	⇔	rhyolite
intermediate	granodiorite diorite	⇔	dacite andesite
mafic	gabbro	⇔	basalt
ultramafic	peridotite		

The porosity of magmatic rocks is mostly formed by micro cracks along the crystal edges and cavities that are not filled by minerals. Hereby is the porosity very low and generally varies from 0 to 1 vol %.

In the rest of the handbook only the general terms granite and basalt will be used; granite for intrusive and basalt for extrusive rocks.



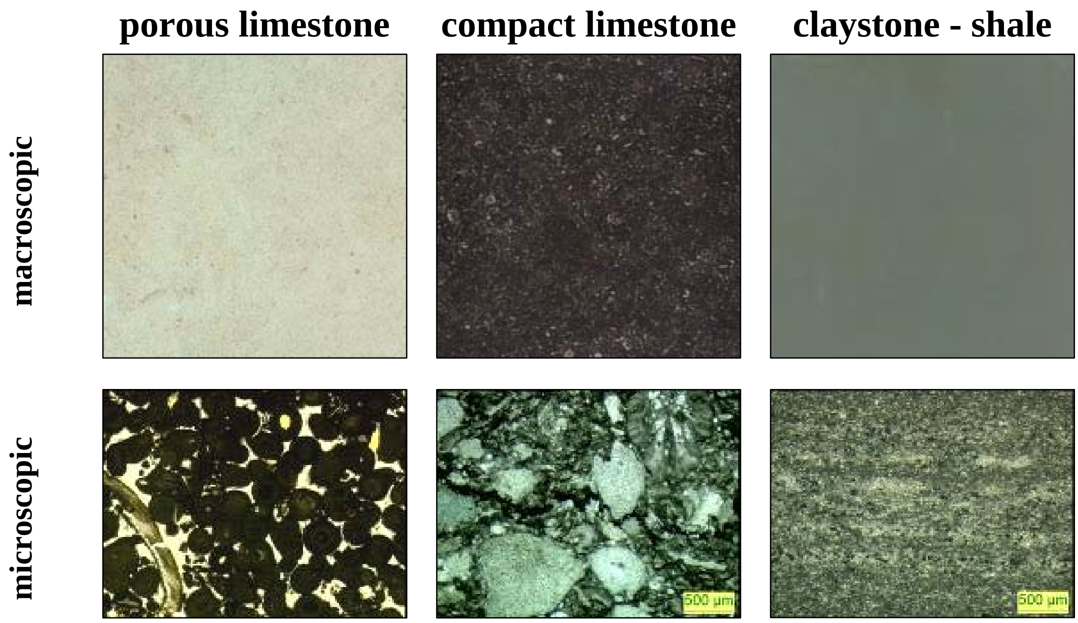
3.2.2 Sedimentary rocks

A sedimentary rock is the product of different processes that occur at the surface part of the rock cycle.

Chemical weathering and mechanical fragmentation of rocks at the surface result in both solid and dissolved products, and erosion carries these materials away. The end products are known as clastic sediments and chemical and biochemical sediments.
Clastic particles are the physically transported solid fragments produced by weathering of pre-existing rocks. These particles range in size from boulders and pebbles to particles of sand, silt and clay. They also vary widely in shape.
The dissolved products of weathering are ions or molecules in the water of soils, rivers, lakes, and oceans. These dissolves substances are precipitated from water by chemical and biochemical reactions. Chemical sediments are formed at or near their place of deposition, usually from seawater. Biochemical sediments contain the mineral remains of organisms or minerals precipitated as a result of biological processes.

When the sediments settle as the wind dies out, water currents slow down, or glacier edges melt; these particles form layers of sediment on land or under the sea. In the ocean or in land aquatic environments, chemical or biochemical precipitates are deposited. As layers of sediment accumulate, older deposited material is compacted and eventually buried in the Earth's crust. When buried, the sediments undergo diagenesis. This term refers to the physical and chemical changes - including pressure, heat and chemical reactions - by which the buried sediments undergo alterations and are lithified/solidified, assuming a new identity as sedimentary rocks.

These different processes make the sedimentary rock group consists out of a large number of diverse stone types. In construction, the following stone types are the most important ones used:



3.2.2.1 Chert

Chert, also called flint, is a hard, compact and dense sedimentary rock made up of chemically or biochemically precipitated silica (SiO_2). The silica in most cherts is in the form of extremely finely crystalline quartz (cryptocrystalline and/or amorphous).
Like calcium carbonate, much silica sediment is precipitated biochemically, secreted as shells by ocean-dwelling organisms. When these organisms die, they sink to the deep ocean floor, where their shells accumulate as layers of silica sediment. After these silica sediments are buried by later sediments, they are diagenetically cemented into chert. Chert may also form as diagenetic nodules and irregular masses replacing carbonate in limestones and dolomites.

3.2.2.2 Sandstone

Sandstones are clastic sedimentary rocks built up from sand. Geologically, sand is formed from medium-sized particles (0,062 to 2 mm in diameter). These sediments are moved by moderate currents, such as those of rivers, waves at shoreline, and the winds that blow sand into dunes. Sand particles may be fine, medium or coarse. If all grains are close to the average size, the sand is well sorted; if many grains are much larger or smaller than the average, the sand is poorly sorted. Sand grains, like other clastic particles, are rounded by abrasion as grains are knocked together during transport. Most sand grains inherit their spheroidal, elongate, or disc shapes of the original crystals in the parent rock.

The mineralogy of a sandstone (or sand) may not match the mineralogy of the parent rocks exactly. Chemical weathering at the source area can alter and dissolve, and thus remove, much of the original minerals, such as feldspar and calcite. Under these conditions the remainder may be grains mainly of quartz.
Sandstones are classified in several major groups on the basis of their mineralogy and texture:

- *Quartz arenites* are made almost entirely of quartz grains, usually well sorted and rounded. These pure quartz sands result from the extensive weathering

that occurred before and during transport and removed everything but quartz, the most stable mineral.
- *Arkoses* contain more than 25 percent feldspar. The grains tend to be poorly rounded and less well sorted than those of pure quartz sandstones. These feldspar rich sandstones come from rapidly eroding granitic and metamorphic terrains where chemical weathering is subordinate to physical weathering.
- *Lithic sandstones* contain many fragments derived from fine-grained rocks, mostly shales, volcanic rocks and fine-grained metamorphic rocks.
- *Greywacke* is a heterogeneous mixture of rock fragments and angular grains of quartz and feldspar, the sand grains being surrounded by a fine-grained clay matrix. Much of this matrix is formed by the chemical alteration and mechanical compaction and deformation of relatively soft rock fragments, such as those of shale and some volcanic rocks, after deep burial of the sandstone formation.

The porosity of a sandstone depends on the degree of cementation. Cementation is a major chemical diagenetic change, in which minerals precipitated in the pores of sediments, forming cements that "glues" the clastic sediments and rocks together. In general, silica, calcite, clay minerals or iron oxides act as cement. Cementation also results in lithification, the diagenetic processes by which soft sediment is hardened into rock. A high degree of cementation leads to a lower porosity of the sandstone. The porosity varies mostly from 0,5 to 25 vol%.

3.2.2.3 Limestone

Limestone is a biochemical sedimentary rock, lithified from carbonate sediments. These carbonate sediments are formed by the accumulation of carbonate minerals precipitated organically or inorganically. The precipitation may occur during sedimentation or diagenesis. The minerals are either calcium or calcium-magnesium carbonates.
Most of the carbonate sediments of the ocean are derived from the calcite shells and skeletons of foraminifera, tiny single-celled organisms that live in surface waters, and from other organisms that secrete calcium carbonate extracted from seawater. When the organisms die, the shells and skeletons settle to the seafloor and accumulate there as sediment. In warm, tropical parts of the ocean, carbonates can also precipitate, inorganically, directly from seawater. These waters are supersaturated with calcium carbonate and precipitate carbonate by the following chemical reaction:

Calcium ion	+	bicarbonate ion *(dissolved)*	→	calcium carbonate *(precipitated)*	+	carbonic acid *(dissolved)*
Ca^{2+}		$2\ HCO_3^-$		$CaCO_3$		H_2CO_3

Limestone is formed from carbonate sands and mud (consisting partly of (microscopic) fragments of shells and calcareous algae and partly of inorganic precipitates).
In the construction area, two major groups of limestone are distinguished on the basis of their porosity:
- **porous limestone** has a porosity between 5 and 50 vol%.
- **compact limestone** shows a 0,2 to 5 vol% porosity.

The compact limestones are formed from muds that are laid down in deep waters or in protected lagoons or bays, where waves and currents do not have the power to carry away the fine particles. These muds become compacted and cemented after burial, forming dense, fine-grained limestone.

A **sandy or clastic limestone** contains as well as calcite as another important fraction of minerals such as quartz and/or glauconite.

3.2.2.4 Claystone - shale

With the sedimentation of a clay suspension, when there are no currents, a clay mud is formed. Usually, such a mud is characterized by a relatively open internal structure that can best be compared with a card house. The clay minerals have a random orientation distribution. This mud has a significant porosity. Fairly quickly the unstable card house will collapse under the influence of the weight of the overlying sediments. The plate-shaped clay minerals undergo a mechanical rotation and orient themselves all horizontally. The porosity is greatly reduced and the water is squeezed out. It gives a weak first anisotropy (i.e. the presence of a preferred orientation) in the rock, parallel to the layering. A **clay stone** is formed. With the subsequent burial of these clay-rich sediments, diagenetic processes provide a subsequent lithification. In addition to a further physical compaction, the clay mineralogy will also change. The resulting rock is a **shale**. It is characterized by an anisotropic structure parallel to the stratification, that represents a first rock cleavage. The rock has a very good fissibility according to these planes.

3.2.3 Metamorphic rocks

Deep in the Earth’s crust, tens of kilometres below the surface, the temperature and pressure are high enough to metamorphose rock without being high enough to melt it. With further increase in temperature and pressure, changes in the chemical environment can alter the mineral composition and crystalline textures of sedimentary and igneous rocks, even though they remain solid all the time.

The pressure and heat, the driving forces of metamorphism, are consequences of three forces:

- the internal heat in the Earth
- the weight of overlying rock
- the horizontal pressures developed as rocks become deformed

Metamorphic changes bring a pre-existing rock more or less into equilibrium with new surroundings. A sedimentary rock formed by diagenesis, for example, is in equilibrium with the moderate pressures and temperatures corresponding to burial a few kilometres deep. Later, this rock may be caught up in an orogeny (i.e. mountain formation) that buries it much deeper and subjects it to a temperature of more than 500 °C. Given enough time - short by geological standards but usually a million years or more - the rock is changed mineralogically and texturally so that it is brought into equilibrium with the new temperatures and pressures. The deeper (and thus hotter) the crust, the faster the metamorphic changes take place.

The physical and chemical factors controlling metamorphism are:

- Heat has a profound effect on a rock's mineralogy and texture. It can break up chemical bounds and alter the existing crystal structures of igneous rocks. As the rock adjusts to its new temperature, its atoms and ions re-crystallize (not so for dynamic metamorphism), linking up in new arrangements and creating new minerals. Many new crystals will grow larger than they were in the original rock, and the rock may become banded as minerals of different compositions are segregated into separate planes.
- Pressure changes a rock's texture as well as its mineralogy. Depending on the kind of stress applied to the rocks, metamorphic minerals may be compressed, elongated or rotated to line up in a particular direction.
- A rock's chemical composition can be altered significantly during metamorphism by the introduction or removal of chemical components by hydrothermal fluids. They rise from the magma, carrying dissolved sodium, potassium, silica, copper, zinc and other chemical elements soluble in hot water under pressure. The elements may be derived from both the magma and the intruded rock. As hydrothermal solutions percolate up to the shallower parts of the crust, they react with the rocks they penetrate, changing their chemical and mineral compositions and sometimes completely replacing one mineral by another without changing the rock's texture.

Table 6: Metamorphosis of sedimentary to metamorphic rock

parent rock (sedimentary)		metamorphic rock
granite - basalt	⇨	gneiss
claystone - shale	⇨	gneiss
	⇨	slate - phyllite - schist
sandstone	⇨	quartzite
limestone	⇨	marble

Within the metamorphic rocks two major groups are recognised:

- the foliated rocks
- the non-foliated rocks

Foliation, a set of flat or wavy, parallel planes produced by deformation, is the most prominent textural feature observed in metamorphic rocks. One of the main causes of foliation is the presence of platy minerals, chiefly the micas and chlorite. Platy minerals tend to crystallize as thin plate-like minerals. The planes of all the platy crystals are aligned parallel to the foliation. The parallel planes are called the preferred orientation of the minerals. As platy minerals crystallize, their planes take a preferred orientation that is usually perpendicular to the main direction of the forces squeezing the rock during the deformation that accompanies metamorphism.

3.2.3.1 foliated rocks

The foliated rocks are classified according to four main criteria:

- the nature of their foliation
- the size of their crystals
- the degree to which their minerals are segregated into lighter and darker bands
- their metamorphic grade

3.2.3.1.1 Slate

Slates are the lowest grade of foliated rocks. These rocks, with their excellent planar layers, are so fine-grained that their individual minerals cannot be seen easily without a microscope. They are commonly produced by the metamorphosis of shales or, less frequently, of volcanic ash deposits. Slates are usually dark gray to black coloured by small amounts of organic material originally present in the parent shale. Slates tinged red and purple get their colour from iron oxide minerals, and greenish slates are coloured by chlorite, a sheety iron silicate mineral closely related to micas.

3.2.3.1.2 Phyllite

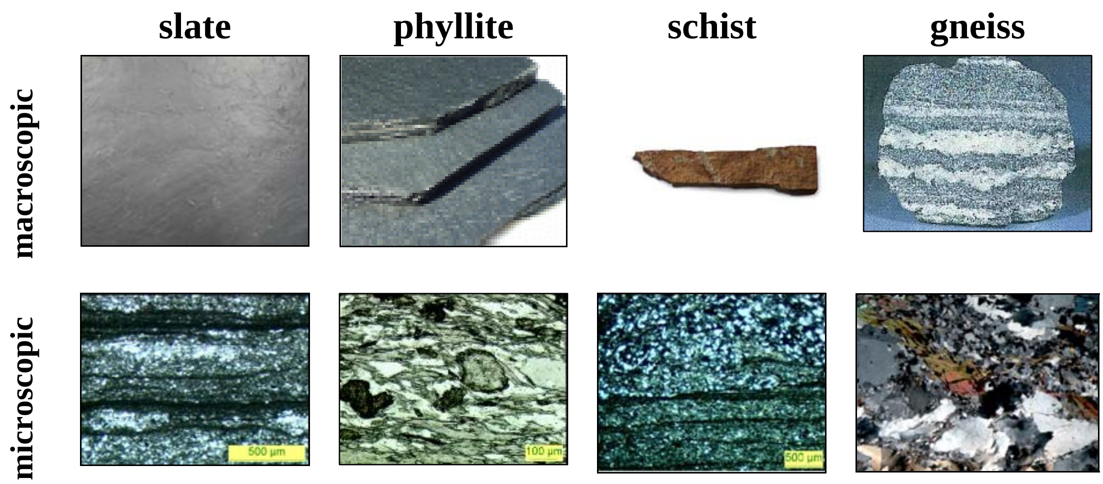
Phyllites are of a slightly higher metamorphic grade than the slates, but of similar character and origin. Phyllites tend to be more or less glossy by crystals of mica and chlorite that have grown a little larger than those of slates. Phyllites, like slates, tend to split into thin sheets but less perfectly than slates.

3.2.3.1.3 Schist

At low grades of metamorphism, crystals of platy minerals are generally too small to be seen, foliation is closely spaced, and layers are very thin. As metamorphic rocks become more intensely metamorphosed, to higher grades, the foliation becomes more conspicuous and pervasive throughout the rock. At the same time, the platy crystals grow to sizes visible to the naked eye, and the minerals may tend to segregate in lighter and darker bands. This parallel arrangement of sheet minerals produces the coarse, wavy, pervasive foliation that is known as schistosity and that characterizes schists. They contain more than 50 percent platy minerals, mainly the micas muscovite and biotite. Depending on the quartz content of the original shale, schists may contain thin layers of quartz, feldspar or both.

3.2.3.1.4 Gneiss

Even coarser foliation is shown by high grade gneisses, light coloured rocks with coarse bands of segregated light and dark minerals throughout the rock. Gneisses do not split along the foliation, and there are few sheetlike, or micaceous minerals, along the foliation planes. Gneisses are coarser grained and the ratio of granular to platy minerals is higher compared to slate and schist (figure 4). The result is a poorly developed foliation and thus little tendency to split. Under conditions of high pressure and temperature, mineral assemblages of the lower grade rocks containing micas and chlorite alter to new assemblages dominated by quartz and feldspars, with lesser amounts of micas and amphiboles. The banding of gneisses into light and dark layers results from the segregation of lighter coloured quartz and feldspar and darker amphiboles and other mafic minerals. Some gneisses may be metamorphic equivalents of sandstones, others of granitic rocks.



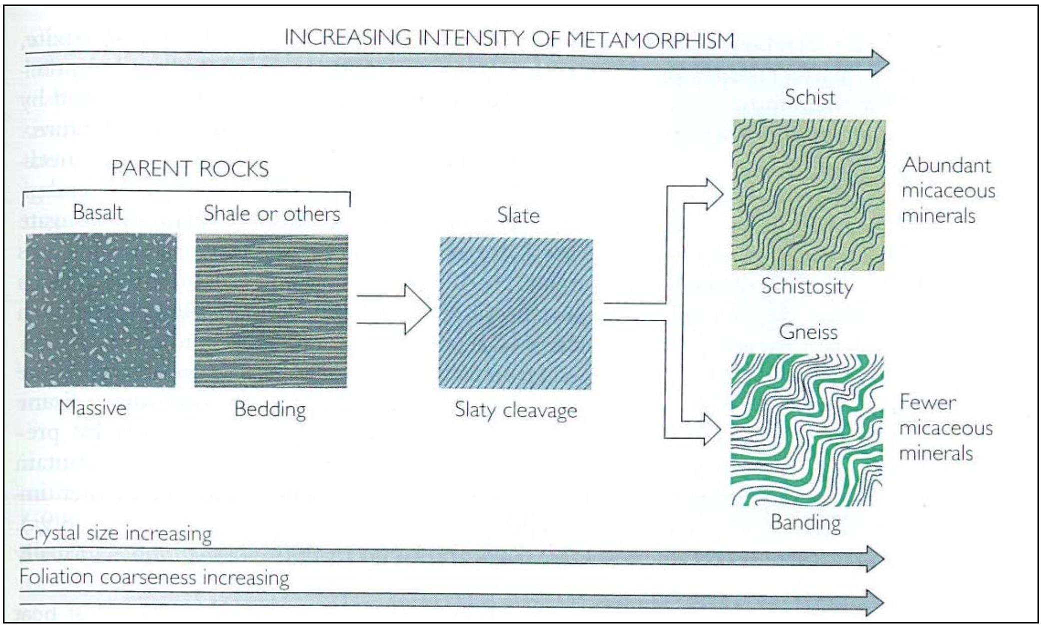


Figure 4

3.2.3.2 Nonfoliated rocks

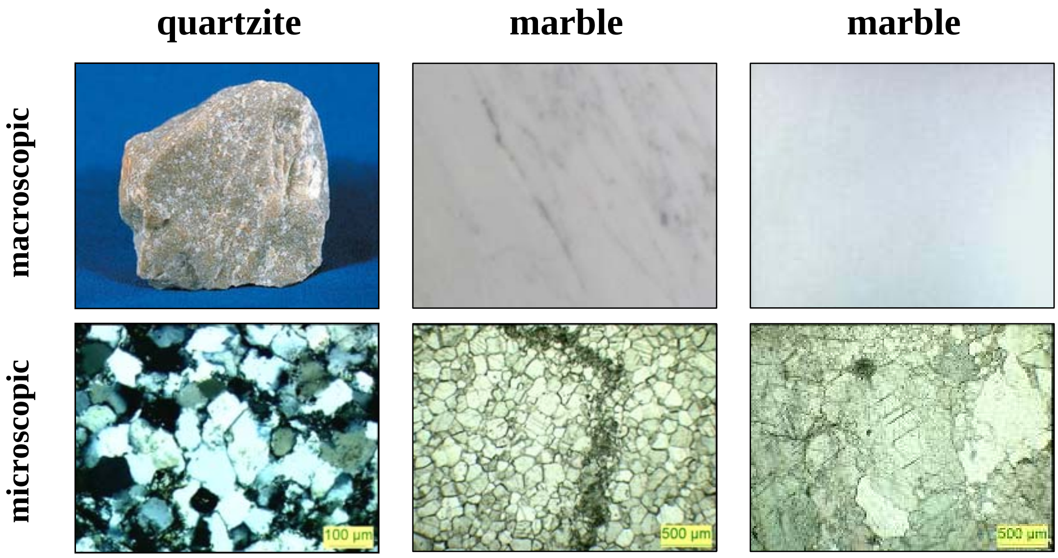
Nonfoliated rocks are composed mainly of crystals that grow in (equidimensional) shapes, such as cubes and spheres, rather than in platy or elongate shapes. These rocks include hornfels, quartzite, marble, argillite, greenstone, amphibolite and granulite. All of them, except hornfels, are defined by their mineral composition rather than their texture. Quarzite and marble are the two types mostly used in the building industry.

3.2.3.2.1 Quarzite

Quarzites are very hard, non-foliated, light grey to white rocks derived from quartz-rich sandstones. Some quarzites are massive - that is, unbroken by preserved bedding or foliation. Other quarzites contain thin bands of slate or schist, relics of former inter-bedded layers of clay or shale.

3.2.3.2.1 Marbles

Marbles are the metamorphic products of heat and pressure acting on limestones and dolomites. Some white, pure marbles, such as the famous Italian marble of Carrara, show an even, smooth texture of inter-grown calcite crystals of uniform size. Other marbles show irregular banding or mottling from silicate and other mineral impurities in the original limestone.



It is important to note that the “Regional metamorphic” processes described above, in many cases, continue until equilibrium with the surroundings. This is in contrast to dynamic metamorphism. Dynamic (cataclastic) metamorphism is metamorphism of rock masses caused primarily by stresses that yield relatively high strain (deformation) rates. The resulting rock texture often shows evidence of in-equilibrium. A feature that also contributes to the behaviour and performance of the specific rock type, also as a building material.

One such example is the degradation of some marble types when used for outdoor applications. Most calcitic marble without equilibrium texture are durable, whereas the ones with equilibrium textures (well developed crystals and straight grain boundaries) are non-durable and lose strength and curve when used as cladding panels. See also under section 6.3.3.3.

4. Stone selection guidance for buildings

As seen in the previous chapters each stone types has its typical characteristics which makes it impossible to use the same stone for every building application or in every climate. Often is said that the best thing to do, is to use local stone types because they are adjusted to the weather circumstances and the people have an experience and tradition for the use of the stone. The first statement is not true. Stones do not adjust to the weather. It is merely a case of accessibility. Before good transportation means where available, local material was the only option and has nothing to do with its durability. In addition, there exists, for a few years, a growing interest for "exotic" stones, from whom their behaviour in our climate is unknown. Here will follow a general guidance to make a first selection based on the stone type and its common characteristics regarding structure and components. ***Nevertheless every new stone type has to be tested before being used in a building because there are always exceptions to the known rules.*** This chapter will give an overview of the different stone types and their potential use in a certain climate and building application.

4.1 Durability of stones depending on the climate

4.1.1 Igneous stones

Granite and basalt are in general very resistant to chemical and physical weathering. They can be used in every type of climate. Because of their good mechanical resistance, they can also be used as load bearing elements in building structures and as ornamental stone elements. Although there are some granites that do not score so well on the mechanical behaviour because they contain a lot of mica's or feldspar that are weathered and have a higher porosity than a granite normally would have.

4.1.2 Sedimentary stones

Because this stone group consists of a number of very different types, some care must be taken. It is of great importance to known what kind of stone that will be used. For example, if one wants to use a **sandstone** in an outdoor application, it has to be known if it is a silica bound sandstone or rather a sandy limestone (calcitic bound). In general, the latter has a lower frost resistance in a humid climate. Sandstones (when they are compact and silica cemented/bound) are rather durable stone elements and can be used for any outdoor application (expect roofing). When the sandstone is quite porous, it is best to use it for indoor applications only, if the climate is humid.

Chert is a very hard and compact stone. It will give no problems in any kind of climate. Only the workability of this stone can be rather problematically. It is not often used as e.g. cladding or floor tiles because it is too hard for an easy polishing.

Porous limestones (and sandy limestone) have a low abrasion resistance and can, in general, not be recommended for use in floor applications (outdoor or indoor). Although they show no high values for flexural and compressive strength tests, they can be used as massive building elements. But in humid climates, they weather strongly and have to be replaced within a century.

Compact limestones can be used for any kind of building application (expect roofing) depending on the climate. However, in very harsh climates and in combination with salt sea-spray or de-icing salts, it can normally not be recommended for applications in contact with or close to the ground.

Shales are slightly layered stones but usually not used as roofing elements. They can be used in the gamut of applications in any kind of climate. Although used in an outdoor application, this kind of stone is only frost resistant when applied with the thickness of the elements equal to the spacing between the layers.

4.1.3 Metamorphic stones

Many metamorphic stones have a low porosity and good bonding between the crystals and thus suitable for external use in every type of climate. **Slate** and **schist** as building material are especially known for their roofing application. However, some types of **marble** can show bowing and severe strength loss when used in a humid climate.

4.2 Guidance tables

One guidance table will be given for each type of climate, with the different stone types used in construction in function of all the possible building applications.

Table 7. EOTA climate A - Severe

STONE TYPES / APPLICATIONS			IGNEOUS ROCKS		SEDIMENTARY ROCKS					METAMORPHIC ROCKS		
			granite	**basalt**	**chert**	**sandstone**	**porous limestone**	**compact limestone**	**shale**	**slate - phyllite - schist**	**marble**	**quarzite**
OUTDOOR	**façade**	**massive elements**	xx	xx	xx	xx	x	x	-	-	xx	xx
		thin slabs	xx	xx	-	xx	x	x	x	xx	xx	xx
		elements in contact with floor	xx	xx	xx	xx	-	x	x	xx	xx	xx
	roofing		-	-	-	-	-	-	-	xx	-	-
	paving	**slabs**	xx	xx	-	xx	-	x	x	xx	xx	xx
		setts	xx	xx	xx	xx	-	x	-	-	xx	xx
		kerbs	xx	xx	xx	xx	-	x	-	-	xx	xx

xx: suitable x : can be used but not recommended -: not suitable

Table 8. EOTA climate B - Moderate

STONE TYPES / APPLICATIONS			IGNEOUS ROCKS		SEDIMENTARY ROCKS					METAMORPHIC ROCKS		
			granite	**basalt**	**chert**	**sandstone**	**porous limestone**	**compact limestone**	**shale**	**slate - phyllite - schist**	**marble**	**quarzite**
OUTDOOR	**façade**	**massive elements**	xx	xx	xx	xx	-	xx	-	-	xx	xx
		thin slabs	xx	xx	-	xx	x	xx	xx	xx	xx	xx
		elements in contact with floor	xx	xx	xx	xx	-	xx	-	xx	xx	xx
	roofing		-	-	-	-	-	-	-	xx	-	-
	paving	**slabs**	xx	xx	-	xx	-	xx	xx	xx	xx	xx
		setts	xx	xx	xx	xx	-	xx	-	-	xx	xx
		kerbs	xx	xx	xx	xx	-	xx	-	-	xx	xx

xx: suitable x : can be used but not recommended -: not suitable

Table 9. EOTA climate C - Light

STONE TYPES / APPLICATIONS			IGNEOUS ROCKS		SEDIMENTARY ROCKS					METAMORPHIC ROCKS		
			granite	**basalt**	**chert**	**sandstone**	**porous limestone**	**compact limestone**	**shale**	**slate - phyllite - schist**	**marble**	**quarzite**
OUTDOOR	**façade**	**massive elements**	xx	xx	xx	xx	-	xx	-	-	xx	xx
		thin slabs	xx	xx	-	xx	xx	xx	xx	xx	xx	xx
		elements in contact with floor	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
	roofing		-	-	-	-	-	-	-	xx	-	-
	paving	**slabs**	xx	xx	-	xx	-	xx	xx	xx	xx	xx
		setts	xx	xx	xx	xx	-	xx	-	-	xx	xx
		kerbs	xx	xx	xx	xx	-	xx	-	-	xx	xx

x: suitable - : not recommended

5. Overview of stone applications in a building

5.1 Outdoor applications

Whether a natural stone can be used for an outdoor application depends mainly on its behaviour in frost conditions. This behaviour is a combined influence of several parameters, concerning the stone itself but also depends on the application and the climate. For example, the application is of great importance, namely a stone used for paving will be more susceptible to frost damage than the same stone applied as cladding units, especially at a distance above the ground level. A climate with a lot of rain combined with freezing temperatures provokes faster damage of the stones than a cold climate without any precipitation. Recommendations for choosing the right natural stone for a specific application are given in chapter 4. Here only a list is given of some different possibilities for the outdoor application of stone. Although the list is far from complete, the different types of application can be said to represent most exposure situations.

5.1.1 Façade

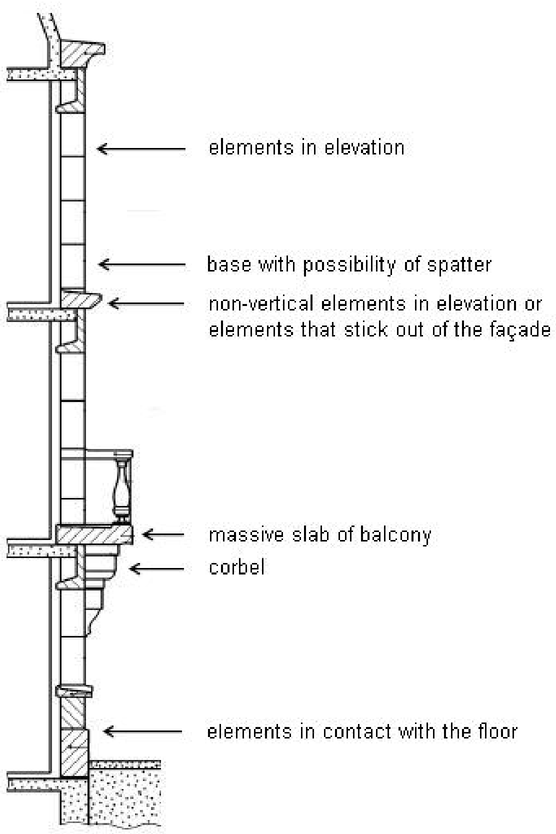


Figure 5: A façade with the different possible stone elements

5.1.1.1 Elements in elevation

These are all the elements that are in line with the face of the building. The elements in elevation can be:

- panels for cladding (they can be fixed to the structure either mechanically or by means of mortar or adhesives), ventilated or not
- masonry units

The elements don't stick out of the face of the building and are subsequently less exposed to the weathering. Except for some marbles which have the intention to bow under influence of rain and sunshine cycles.

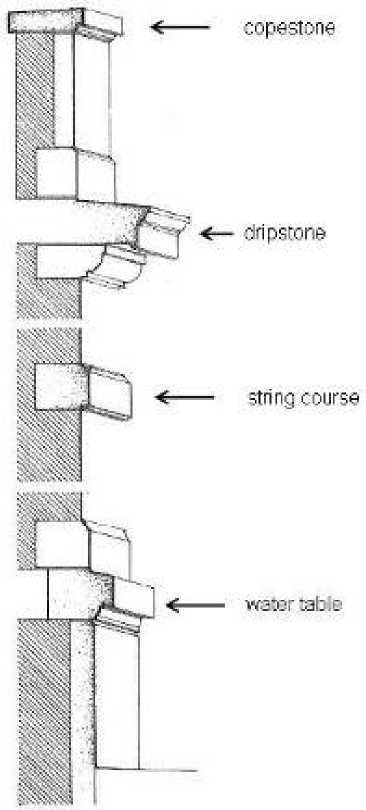
5.1.1.2 Base with possibility of spatter

These elements are also in elevation but are placed just above an element that sticks out of the façade of the building. Because of this type of construction, the rain drops will scatter back against the natural stone in elevation and be absorbed. When there is a possibility of spatter the stones just above will be more saturated than the other elements in elevation.

5.1.1.3 Non-vertical elements in elevation or elements that stick out of the façade

This type of building stones will absorb a lot of water because it is directly exposed to the rain. This category includes stone applications such as:

- Copestones: a stone forming a coping. (*figure 6*)
- Dripstones: a stone moulding used as a drip, such as on a cornice over a window or doorway. (*figure 6*)
- String courses: a horizontal course of stone flush with or projecting beyond the face of a building, often moulded to mark a division in the wall. Also called belt course. (*figure 6*)
- Water tables: a projecting string course, moulding or ledge placed so as to divert rainwater from a building. (*figure 6*)
- Skew corbels: a stone overhanging at the foot of a gable coping, often serving as a stop for eave gutters or wall cornices. (*figure 7*)
- Kneelers: any of the stones having a sloping top for supporting or forming a gable coping. Also called skew. (*figure 7*)
- Corbie steps: any of a series of step like projections that terminate a masonry gable above the surface of the roof. Also called crowstep. (*figure 8*)
- Massive slab or balcony (*figure 5*)



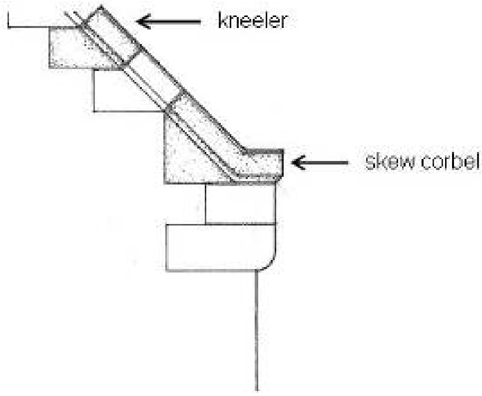


Figure 7

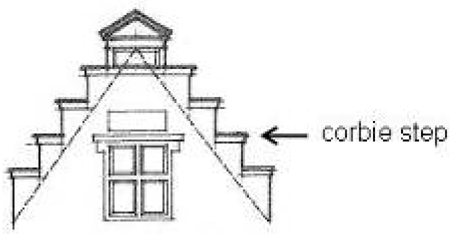


Figure 6

Figure 8

5.1.1.4 Corbel

A corbel is an ornamental stone that is placed under a structure and sticks out of the face of a building in order to support it. Because of its position, a corbel will be protected from the rain

5.1.1.5 Elements in contact with the ground

These building elements are mostly called plinths. It is a continuous, usually projecting course of stones forming the base or foundation of a wall. Since it is in contact with the ground, it not only absorbs water deriving from the rain but it also takes up water by capillarity from the groundwater that often contains salts (if no water tightness barrier has been installed) or by spattering from the adjacent ground. These elements can also be exposed to de-icing salts.

5.1.2 Roofing

The natural stones most frequently used as roofing tiles, are the easily cleft slates (or phyllites).

The dimension and type of slate are chosen depending on what kind of rooftop that is desired:

- **Standard slate roof**

A "Standard" slate roof is composed of slate approximately 50 mm thick. The pieces are of a uniform standard length and width and are cut with a square tail (or butt) which is then laid to uniform horizontal lines.
Applying two or more sizes on the same area, will not only give a variable visible pattern but also create additional shadows and shading.

- **Textural slate roof**

A "Textural" slate roof designates pieces of material having a rougher texture than the "Standard" and perhaps uneven tails. They may even display variation in thickness or size. Different shades may be used to enhance the colour effect of the overall design.

- **Graduated slate roof**

A "Graduated" slate roof is a combination of the "Textural" slate utilizing even more modifications in thickness, size and exposure. The thickest and longest pieces are generally placed at the eaves and gradually decrease in size and thickness going up to the ridge

5.1.3 Paving

Before applying a natural stone for external paving not only the frost resistance including de-icing salts has to be assessed but also the abrasion resistance in function of its use (e.g. extensive use in a railway station). Another important characteristic to test is the compressive or flexural strength (for kerbs/setts and slabs respectively), in order to fix the maximum load they can carry. In some applications, the slipperiness is also an important property to consider.

Some examples of paving are:
- a terrace of a private house
- a public square
- the sidewalk
- …

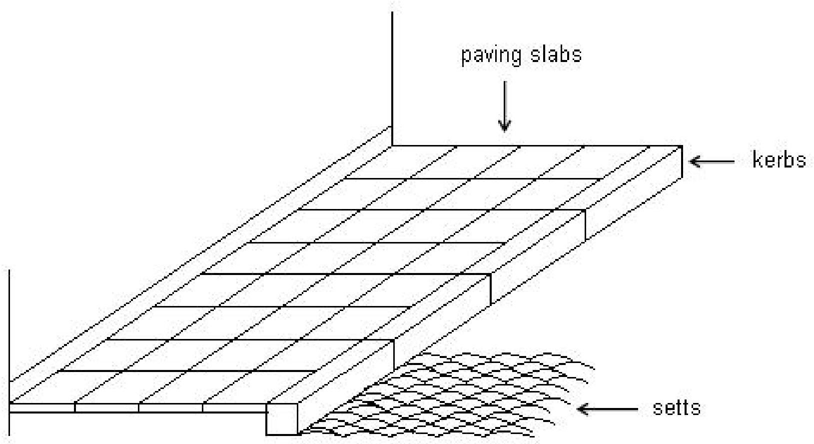


Figure 9: The different elements of paving

5.1.3.1 Slabs for paving and stairs

According to EN 1341:2001, a slab for paving is a flat piece of natural stone with a nominal length of more than 150 mm and is generally equal to less than twice the thickness. In general, paving units are placed directly in a sand foundation or on cement stabilized foundation. Stair units can also be mechanically fixed to a structure. (*figure 4*)

5.1.3.2 Setts

According to EN 1342:2001, a sett is a small natural stone paving block with work dimensions between 50 mm and 300 mm and no plane dimension generally exceeding twice the thickness. The minimum nominal thickness is 50 mm. The setts are normally placed in a stabilized sand foundation. (*figure 4*)

5.1.3.3 Kerbs

According to EN 1343:2001, a kerb is a natural stone unit greater than 300 mm in length. It can be curved in plan with a convex or concave face. They are commonly used as edging to a road or footpath. (*figure 4*)

5.2 Indoor applications

For indoor applications, the durability of the aspect of the stone is also very important. The stone pathologies that can appear are rather diverse. It can go from discolouration due to bad cleaning to flaking due to expansive minerals in the stone itself.

Almost all damages are triggered by humidity. The quantity of water that comes in contact with the natural stone has to be followed up meticulously from the placement of the stone to the every day maintenance.

5.2.1 Wall covering

For wall covering tiles, a thickness > 6 mm is generally recommended. They are fixed to the foundation either mechanically or by means of mortar or adhesives. If the stone is known to be susceptible to stains, a mortar consisting of white sand and low alkali cement (e.g. white cement) is recommended. In bathrooms or other humid places one has to use stone types that have a low capillary absorption velocity and do not contain swelling minerals/components.

5.2.2 Floors and stairs

According to EN 12058:2004, floor tiles are flat natural stone elements with a nominal thickness > 12 mm that are fixed on the foundation by mortar, or another type of fixing agent.

The following four placing techniques are the most commonly used ones for flooring units:

- placing with mortar on a stabilized sand bed (*figure 10*)
- placing with mortar on hardened screed (*figure 11*)
- placing with cementitious adhesive on hardened screed (*figure 12*)
- placing in fresh screed

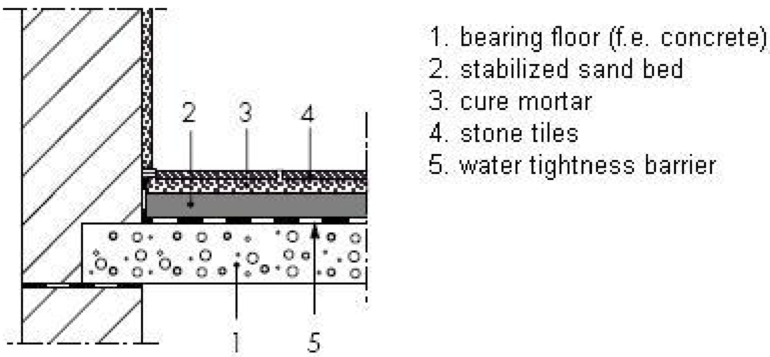


Figure 10: Placing with mortar on a stabilized sand bed

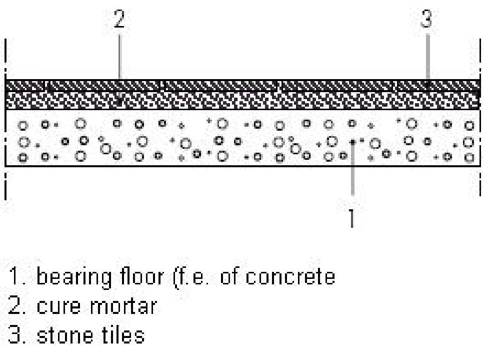


Figure 11: Placing with mortar on a hardened screed

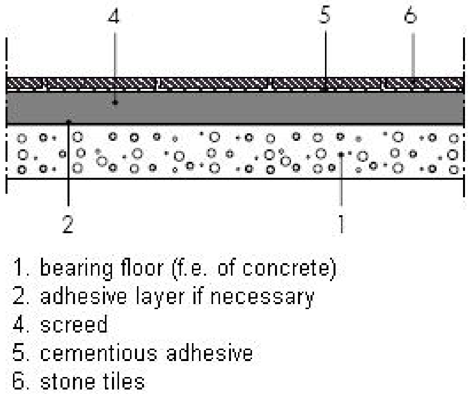


Figure 12: Placing with cementitious adhesive on a hardened screed

The choice of the placing method depends on the dimensions of the tiles/slabs and the levelness of the foundation. When choosing the placing technique, one has to bear in mind that the amount of water that eventually is transported through the stone tile is a function of the placing method. (*table 7*)

Table 10: Amount of water, which can be absorbed by a stone, as a function of the placing

mode of placing	amount of water L/m²
traditional placing (mortar bed)	5 - 7
placing in fresh screed	10 - 13
placing with cementitious adhesive on hardened screed	0,7 – 1

5.2.3 Tablets

Tablets are natural stone elements that are used as window sills or kitchen tablets. In this application, especially kitchen tablets, external staining is an important issue to take into account. External stains are here defined as stains that are induced by a reaction with substances that appears by accident e.g. by spilling.

6. Proposal for a complete set of specifications

There are many ways to characterize natural stone, from the very scientific and detailed approach to the practical one. In this chapter, we will concentrate on the characteristics that are important to know, in order to have a reliable conception of its ability to be used in construction. These characteristics are grouped in the following 3 categories (*figure 5.2*):

- *Identification*: the ones important to identify the characteristics of the raw material. (*cf. chapter 5.2.3.1*)
- *Performance in use*: the ones that evaluate how the material will perform once transformed in a finished product and put in place in the construction. (*cf. chapter 5.2.3.2*)
- *Durability*: the ones that allow for prediction of how the stone element will behave in time and how stable its initial performances will be. (*cf. chapter 5.2.3.3*)

For each characteristic, the reference European test method is given and shortly described. *Enclosure 1* gives an overview of the most relevant and used tests for each specific application of a stone. They are also quoted in function of their importance.

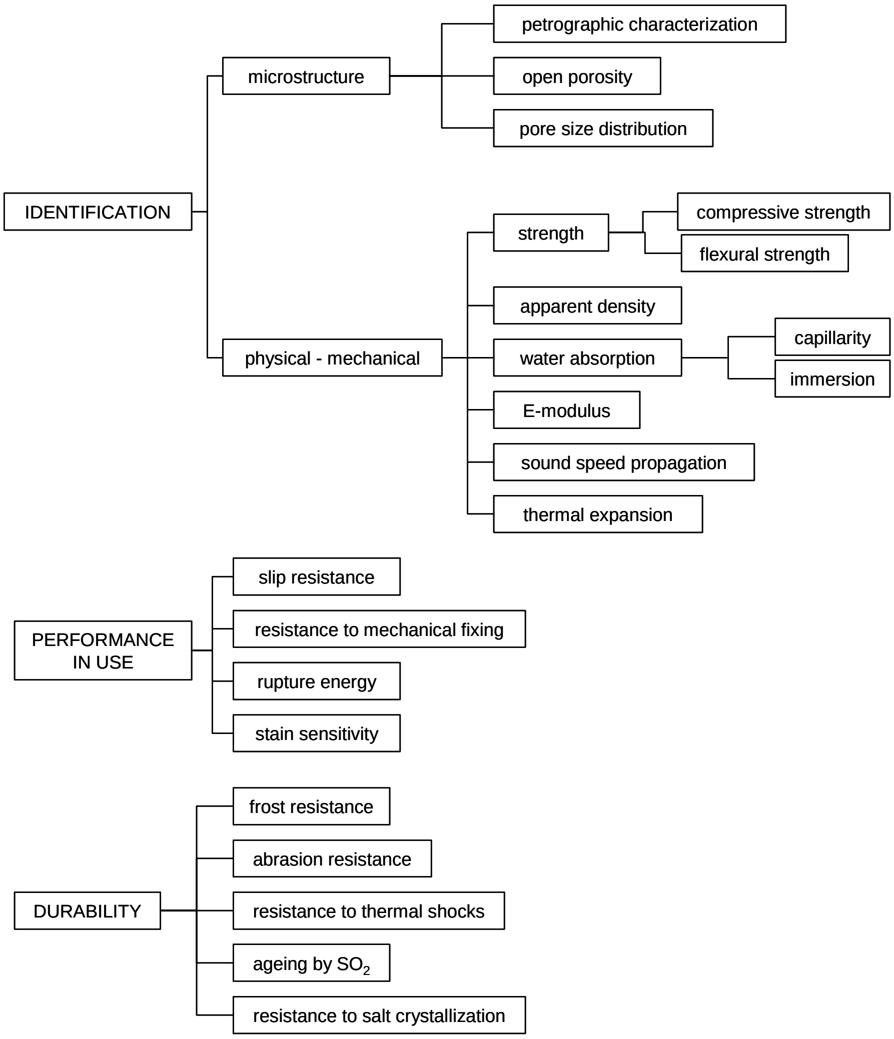


Figure 13: Classification of the different characteristics of stone

Another important aspect regarding stone characteristics is the present transition to use of the European CE-marking (*table 11*).

Taking into account the lack of experience with the new standards and the state of knowledge of the participating laboratories in this field, this part will try to give an overview of the most important characteristics of natural stones to be known and to propose some criteria for a sound selection of the type of stone in function of its use. This first proposal will be adapted and completed as Task 5.1 of this project advances.

Table 11: CE-marking

Type of product	**Use**		**CE-marking**
setts	external paving		since October 2003
kerbs	external paving		since October 2003
slabs	external paving		since October 2003
	floor and stair covering (internal and external)		since March 2005
	walling and ceiling finishes (internal and external)		since March 2005
	cladding (external)		since March 2005
modular tiles	floor and stair covering (internal and external) walling and ceiling finishes (internal and external)		since March 2005

The logos will identify if it is a characteristic to declare in the frame of the CE-marking and for which specific application of the stone. This implies that the user should find the value of this characteristic on the packaging and/or the accompanying commercial documents.

6.1 Identification characteristics

6.1.1 Characteristics concerning the microstructure

6.1.1.1 Petrographic characterization

Petrographic characterization allows the determination of the mineralogical composition of the natural stone. Based on this information the right geological name of the stone can be deduced. According to EN 12440, the information of the stone has to reveal the land of provenance, the (geological) type and the colour of the stone. In this frame, the correct petrographical identification of the stone is important and should avoid the use of abusive appellations, as it is often the case on the market.

Besides these geological features, it can give also information about the porosity, state of weathering, chemical, physical and mechanical characteristics of the stone. (*fig. 14*)

Reference: EN 12407 & EN 12670
Test: Thin sections, with a thickness of 25 - 30 µm so that they let light through, are made of the natural stone and examined with a petrographic microscope. Also a procedure for macroscopic description of the material is included.

6.1.1.2 Open porosity

The open porosity has a direct relation with important characteristics such as the mechanical strength and the behaviour in presence of liquids (water or potentially staining products). The mechanical strength decreases with increasing porosity and liquids can be more easily absorbed (more sensitive to staining) by the stone. (*figures 14 and 15*)

Reference: EN 1936
Test: The porosity is mathematically derived from the test for the determination of the apparent density and expressed in volume %. It represents the percentage of open spaces in the stone.

6.1.1.3 Pore size distribution (MIP: Mercury Intrusion Porosimetry)

The pore size distribution *(figure 15)* of the stone is important to know, because it determines essential characteristics, such as the frost resistance (which is not directly related to the open porosity). The frost action inside a porous material is a very complex phenomenon. It is generally accepted that the most dangerous stresses will be induced by the crystallization of ice in the smaller pores, while the non-capillary, larger ones, will provide space for the expansion of ice, reducing in this way the stress intensity in the material. Nevertheless the characterization of the pore size distribution is not a test commonly asked for and is more important for scientific researches.

Reference: ISO/WD 15901-1
Test: Determination of the size and the distribution of the pores by intrusion of mercury under different pressure conditions. Other techniques such as gas adsorption by BET together with SEM are also used to cover the entire range of pore sizes.

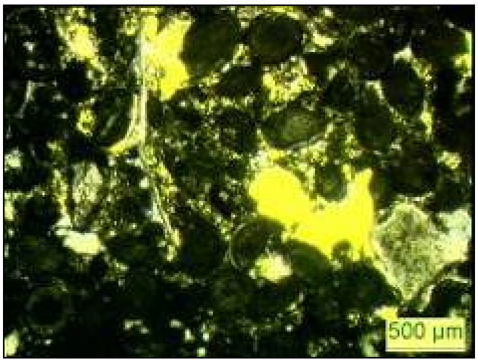


Figure 14: A thin section of the limestone "Massangis Roche Jaune". The yellow spots are pores.

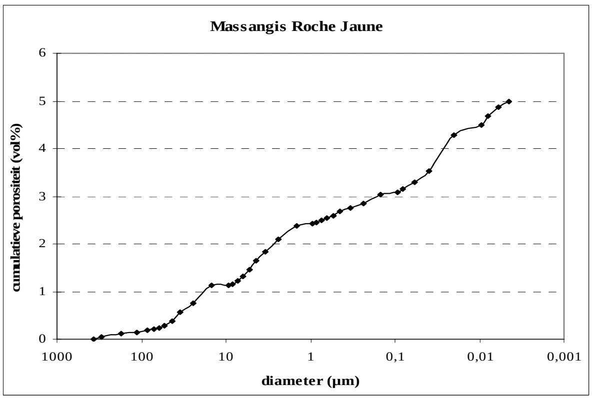


Figure 15: The distribution of the dimension of the pores present in the limestone "Massangis Roche Jaune".

6.1.2 Physical – mechanical characteristics

6.1.2.1 Strength

This is clearly an essential characteristic to know for load-bearing applications (cf. for example prEN1996-1-1, “Eurocode 6 – design of masonry structures).

- **Compressive strength**

  The uniaxial compressive strength is the load per unit area under which a block fails by shear. This property is not frequently asked for and tells little of use that can’t be told by other tests. The compressive strength of natural stone is by far surpassing that of e.g. concrete and can’t normally be made use of.

  Reference: EN 1926
  Test: The samples, with rectified surfaces, are placed and centred on a platform of a press. The load of the press is continuously increased until rupture.

- **Flexural strength**

The flexural strength represents mainly the resistance to flexure deformation of the bed and the natural stone.

Reference: EN 12372
Test: The samples, with standardized dimensions, are placed and centred on a two bars. A concentrated load exerts pressure that is continuously increased, on the sample until rupture (figure 16). This gives a value of flexural strength of the natural stone. There is a need to review this test since too many dimensions are allowed for and give different results.

Figure 16: Flexural test

6.1.2.2 Apparent density

This property is defined as the ratio between the mass of a dry specimen and its apparent volume (i.e. the volume limited by external surface of the specimen, including any voids). The apparent density reflects the degree of compaction of the stone and makes it possible to estimate the weight of a known volume.

Reference: EN 1936
Test: After drying to a constant mass, six samples are weighed. They are placed in a vessel and under vacuum conditions will absorb water that is added. After a certain time the samples are weighed wet (lightly wiped with e.g. a chamois leather) and under water. With these three weights it is possible to determine the apparent density.

<u>Note</u>: for carbonate rocks, the drying of the samples should be done at 40 °C for a longer period of time instead of 70 °C (as described in the standard). Several carbonate rocks start to loose strength already slightly above 40 °C. This will affect the measurements of porosity, strength, E-modulus. This recommendation is applicable for the test where the samples must be dried.

6.1.2.3 Water absorption

Absorption reflects the ability of a stone to take up liquids and gases. But mostly water absorption tests give valuable information because the right application for the stone can be determined. For example, it is not recommended to use a natural stone with a large water absorption capacity in applications where the stone can be directly in contact with water (for example bathrooms, but also floorings and all external elements in contact with the ground). Moreover, water absorption can provoke stains, salts migrations, inclusion of dirt in the surface texture, etc.

- **Water absorption coefficient by capillarity**

  The water absorption coefficient is a measure for the amount water that a stone can absorb in a given time.

  Reference: EN 1925
  Test: After drying to a constant mass, the specimen is placed with one of its sides (never the working surface) in 3 ± 1 mm water. The increase of the mass is measured in function with the time.

  Recommendations: It is considered that values above 100 $g/m^2.\sqrt{s}$ are characteristic for stones with a high capillary absorption.

- **Water absorption at atmospheric pressure**

  This test gives a value for the amount of water that can be absorbed by the stone when immersed in water.

  Reference: EN 13755
  Test: After drying to a constant mass, each specimen is weighed and then immersed in water at atmospheric pressure for a specified period of time. The ratio of the mass of water absorbed by each specimen when constant mass is reached is determined.

6.1.2.4 The dynamic modulus of elasticity

The dynamic modulus of elasticity is an indirect measure for the strength of the stone. It is a useful property to test before and after a durability test to see if the strength and internal structure is changed (for example, microcracks).

Figure 17: Measuring E-modulus

Reference: EN 14146
Test: The dynamic modulus of elasticity of the stone is calculated from the fundamental resonance frequency that is measured with a special device. Vibrations are generated on the samples (prismatic or cylindrical) e.g. by a little stroke of a little hammer. The special device transforms the vibrations into the fundamental resonance frequency that can be read on the display (figure 17).

Recommendations: The reduction in dynamic E-modulus should not be more than 30 % after any durability test.

6.1.2.5 Sound speed propagation

The sound speed through the stone is defined by nature and condition of the tested stone: porosity, moisture content, mineralogy, micro-cracks, etc. The sound speed determination is an accurate, non-destructive, simple method to define the homogeneity and to distinguish the difference in quality of the tested stone. Sound speed measurements can also be carried out in situ.

Reference: prEN 14579
Test: A pulse of longitudinal vibrations is produced by an electro-acoustical transducer held in contact with one surface of the tested stone. After traversing a known path length in the stone, the pulse of vibrations is converted into an electrical signal by a second transducer and electronic timing circuits enable the transit time of the pulse to be measured.

6.1.2.6 Thermal expansion coefficient

By applying natural stone elements one has to bear in mind that natural stone, as any building material, is subjected to thermal deformation. This is particularly important for the dimensioning of external floor, façade elements and joints (figure 18). Experiments on facades have shown that the temperature of a dark stone cladding can reach 80°C.

Reference: prEN 14581
Test: After drying to a constant mass, the length of the sample is measured, usually in one direction which is parallel to the plane of anisotropy. Subsequently the sample is brought up to at least two different temperatures and the length is measured each time the given temperature is reached and stabilized for a certain time. The linear thermal expansion coefficient is calculated from the difference in length at the two temperatures.

Note: It is crucial for the assessment of the performance to measure the combined thermal and moisture induced expansion. In reality, the stone elements are subjected to this. The combination of the two types of expansion can induce a permanent dilation which is 10 – 100 times larger than the one generated by a dry expansion.

Figure 18: Cracks on cladding thermal (and moisture) expansion.

6.2 Performance of the stone in use

6.2.1 Slip resistance

Slip resistance of the surface of natural stone is an important characteristic concerning the safety of a floor. When the surface finish of a stone yields a low slip resistance value, the risk of slipping while walking is evident. It is generally considered that a slip resistance of more than 35 is safe. Coarse textured (relief > 1mm) and riven units are assumed to give a satisfactory slip resistance value.

Reference: EN 14231
Test: The slip is tested with a pendulum apparatus on the surface (with a certain finish) of the natural stone. The pendulum tester consists of a spring loaded slider made of a standard rubber attached to the end of the pendulum. When swinging the pendulum, it measures the friction between the slider and the test surface and provides a standardized value of slip resistance (figure 19).

6.2.2 Resistance to mechanical fixing

The determination of this property is important for the design of a façade cladded with thin stone slabs. Usually, codes of practice need the value, provided by this test, to check if the slabs and their mechanical anchoring system are correctly designed towards wind pressure and mechanical shock.

Reference: EN 13364
Test: The test consists of applying a force in a direction perpendicular to the face of a stone sample through a dowel previously placed in a hole drilled in one of its sides and measuring the breaking load of the sample
(figure 20).

Figure 20: Traditional anchoring system with dowels

6.2.3 Rupture energy

This test gives an idea of the magnitude of impact that a natural stone tile can sustain before rupture. It is an important characteristic for the applications that can be subjected to hard body impact (essentially floorings, but also the lower parts of a façade).

Reference: EN 14158

Test: After drying each specimen to a constant mass the energy of rupture by impact is determined by the dropping of a spherical steel ball (with a mass of 1 kg) from given increasing heights until the specimen breaks.

Recommendations:

When tested according to EN 14158 (slabs on a sand bed), we recommend the following minimum heights before rupture:

Table 12

Use	**Height before rupture (cm)**
Individual	30
Moderate	45
Intensive	60

Note: Hard body impact resistance of a stone system depends on the stone characteristics, but also on the fixing system and on the underground. The test result is also influenced by the surface finish. A bush hammered surface may dampen the impact and thereby neutralize some of the induced stresses. So, it is recommended to test the system in real conditions of use, i.e. for example a flooring tile embedded in mortar on a concrete slab. When tested in these conditions, the recommendations become:

Table 13

Use (cf table 11)	**Height before rupture (cm)**
Individual	100
Moderate	150
Intensive	200

Figure 21: Test results illustrating the influence of the setting : the tile alone (bottom) doesn't resist a drop of 35 cm, while the same tile embedded in a mortar of 2cm thickness breaks at 60cm (upper right). If the mortar is settled on a concrete slab, no damages are observed after a drop of 200cm (upper left)

6.2.4 Stain sensitivity

Sensitivity to internal staining is a characteristic dealing with aesthetic quality and is consequently impossible to specify. That means that the limit between what is acceptable and what is not cannot be unvaryingly fixed and that the results of the hereafter proposed tests have to be interpreted accordingly. In fact, a stone can be sensitive to three kinds of stains:

6.2.4.1 Stain type I

This type of stain is due to oxidation of iron bearing minerals (pyrite, biotite, …) present in the stone. Depending on the size of these minerals, the stains will appear as yellow to brown spots (in case of outcropping minerals) (*Figure 22*), or diffused shadows on the surface (in the case of finely dispersed minerals) (*Figure 23*). Both types are very difficult to remove and studies have shown that they need different tests conditions to reproduce in laboratory.

Figure 22:Limestone

Reference: EN 14066 (only for stones with outcropping iron bearing minerals)
Test: see "Thermal shock test"

Note: for stones with finely dispersed, non visible iron bearing minerals, like some white marbles, a adapted thermal shock test is proposed: 20 cycles consisting of 6h in an alkaline solution (1M & pH=9, obtained by dissolving $NaHCO_3$ in water), followed by 18h in an oven at 55 ± 5 °C.

Figure 23: Marble

6.2.4.2 Stain type II

This type of staining is induced by a reaction of organic matter (in the stone) with alkalis deriving from the cement. The staining appears as a brown shadow/film on the surface of the slabs, a few days after the placing. These stains are relatively soluble in water and normally easy to remove. Until now, no normalized test does exist to reproduce the staining type II in laboratory conditions.

Reference: adapted Venuat test
Test: four stone tiles embedded in mortar (white sand & white cement). After hardening, the units are placed in demineralised water at 20 °C & 60 % RH, only the base of the units is in contact with the water.

6.2.4.3 External stain

External stains are induced by a reaction with substances that appear at a bad moment and in a bad place. Until now, no standardised test, specific for natural stone do exist.

Reference: I-STONE method now introduced as a new work item in CEN TC 246 (figure 24).
Test: One "spills" substances that are known for their staining of natural stone. Substances, like ketchup, red wine, cooking oil, soft drinks, coffee etc dropped on the stone. The chosen substances cover a wide range of applications. After the application of the substances, they are cleaned with water and soft soap after 24 hours.

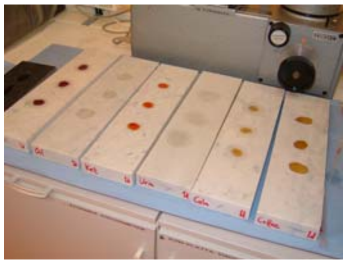


Figure 24: spilled substances

6.3 Durability characteristics

6.3.1 Frost resistance

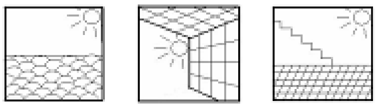


Figure 25: Cracks due to frost

Freeze-thaw resistance is certainly the most important issue to consider when specifying stone for external use. Because if frost damage occur, it is so destructive that the affected stone elements are generally smashed to pieces, threatening the service life of the whole building. Unfortunately, this is also one of the most difficult stone properties to evaluate and especially in the case of natural stone where the following difficulties have to be overcome:

Figure 26: Stone destroyed due to frost

- "natural stone" is a generic denomination gathering a large number of materials with a very broad variation of characteristics. A frost test suitable for all types must take this into account. For example, the water impregnation method must be suitable for granites with a very low porosity as well as for very porous limestones.
- unlike manufactured materials, which are designed for one specific use, natural stone has many possible applications in a building and one type of stone can be suitable for only a few of them. Consequently, a frost test for natural stone must have one or more varying parameters (impregnation level and/or number of cycles) to allow for the simulation of the different stresses on the material in function of its use.

6.3.1.1 The critical parameters which define different categories of use

For a given climate, a classification for the intensity of the frost action on the **different external parts** of a building can be the following (from the highest to the lowest):

- paving and flooring
- elements in direct contact with the ground (base courses, plinths, socles,...)
- non vertical parts in elevation and all elements sticking out of the facade (cornices, mouldings, windowsills, ...)
- solid masonry units (non-ventilated wall, that is with no possibility of drying from the back face of the stone units)
- wall cladding units or cavity wall units with ventilation allowing the drying from the inner face

The intensity of the stress is also depends on the **type of climate**. The relevant parameters to define the severity of a climate in respect to frost action are:

- the intensity of the rain fall during the winter period
- the number of freeze/thaw cycles during one winter

There is, up to now, no official classification of the climatic zones in Europe concerning the frost action. But by combining these two parameters, it's possible to define a critical climatic event as a frost period preceded by a certain quantity of rain, which is likely to affect the durability of the exposed material when repeated.

For example, climatic data in Belgium show that external paving materials undergo between 20 and 30 critical climatic events (CCE) per year, which is considered as a severe climate towards the frost action. On this basis, we can define the following climate classes:

Table 14

Type of climate towards frost action	**Number of CCE during one year** (paving exposure as a reference)
severe	more than 20
moderate	between 10 and 20
light	less than 10

6.3.1.2 Tests

- **Identification test**

  Reference: EN 12371 (presently under review)
  Test: The samples undergo a number of cycles consisting of frost in air and thawing in water. After each 14 cycles, the samples are controlled in order to determine any damages. When a defined frost damage is observed, the test is completed and the number of cycles (240 cycles is the maximum) that had been carried out is an indication of the frost resistance (although no specifications are yet developed).

- **Technological test**

  Reference: EN 12371 & EN 1926 or EN 12372
  Test: The samples undergo 48 or 12 cycles of frost in air and defrost in water, followed by a compression or flexure test (according to the type of application).

At the moment of reporting, an additional test is drafted within TC 246/WG 2 test methods, by an I-STONE partner. The test is directed to the combined effect of salt and frost. The test is more severe that the standard one and it is anticipated that it will be especially well used in the Nordic countries.

6.3.1.3 Recommandations for use

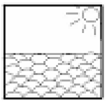
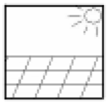
The European test method is only available since October 2001, this means that sufficient experience is lacking in order to give reliable specifications based on its results. However, the experience so far allows us to propose, as a first estimation, the following: when tested according to EN 12371 – identification test, the stone should at least pass the following number of cycles:

Table 15

USES \ CLIMATE		LIGHT	MODERATE	SEVERE
EXTERIOR	paving and flooring units	48 (*)	98	154
	elements in contact with the floor	48	98	154
	non-vertical elements in elevation or elements that stick out of the facade	28	56	84
	solid masonry units	12	28	70
	facade cladding units	0	12	48

(*) declared value for CE-marking

6.3.2 Abrasion resistance

Abrasion can be defined as the wear caused by fine solid particles. It is certainly the most important form of stress on natural stone slabs, as far as flooring and paving are concerned.

A floor, badly designed in function of abrasion resistance, will rapidly wear and its surface finish will change (loss of brilliance, modification of the colour, …) in the most walked areas. Sometimes, the abrasion effect will provoke the formation of a “patina” on stones composed of essentially one mineral (limestones).

6.3.1.1 The influent parameters which define different categories of use

The intensity of the pedestrian traffic on the flooring is the parameter that has to be considered first. From the entrance hall of a station to the private bathroom, there are many different degrees of traffic intensity.

Moreover, it is generally recognised that wear resulting from the movement of pedestrians is most severe in places where changes of direction occur and where people are moving in a confined area, for example moving slowly through a ticket barrier.

A possible classification of uses taking into account these effects can be the following:

Table 16

Use	Examples
Intensive	. public halls in stations, airports, shopping centres . halls in apartment block with more than 30 housing units . common rooms of office building with more than 50 employees . floorings in supermarkets, …
Moderate	. common rooms of multifamily houses (with max. 30 housing units) . common rooms of block offices (max. 50 employees) . rooms with moderate commercial use
Individual	. all rooms in private housing units *note : in this category, the areas most susceptible to wear are the ones which are directly accessible from outside*

6.3.2.2 Tests

Reference: EN 14157

Test: The standard describes three possible tests, the first one being considered as the reference:

- Method A: wide wheel abrasion test (Capon) (*figure 27*)

  The test is carried out by abrading the face of a sample which will be exposed in use with an abrasive material or wheel under standard conditions. The wear is determined as the width of the groove in the sample.

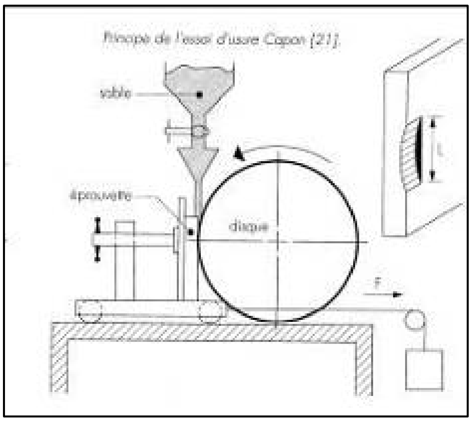


Figure 27: Wide wheel Capon - principle

- Method B: Böhme abrasion test

  The test specimen is placed on the test track of the Böhme disc abrader on which standard abrasive is poured, the disc being rotated and the specimens subjected to an abrasive load of 294 ± 3 N for a given number of cycles. The wear is determined as the loss in sample volume.

- Method C: Amsler abrasion test

  Samples are placed on the Amsler disc on which standard abrasive is poured, the disc being rotated and the samples subjected to an abrasive load for a given number of cycles. The wear is determined as the loss in sample thickness.

6.3.2.3 Recommendations for use

Table 17 shows indicative values for the use of a natural stone in a particular application. It is important to note that these values are currently subjected to additional research so that the divisions should not be taken as absolute. Especially since the comparative results (*table 17 & figure 28*) have shown a poor correlation between the Capon test and the other two abrasion tests, especially between 20 and 30 mm (Capon test).

Table 17

USE / TEST METHOD	INDIVIDUAL	MODERATE	INTENSIVE
Capon wide wheel (mm)	≤ 42	≤ 35	≤ 24
Böhm	??	≤ 38	≤ 27
Amsler (mm/1000m)	≤ 12	≤ 8	≤ 4

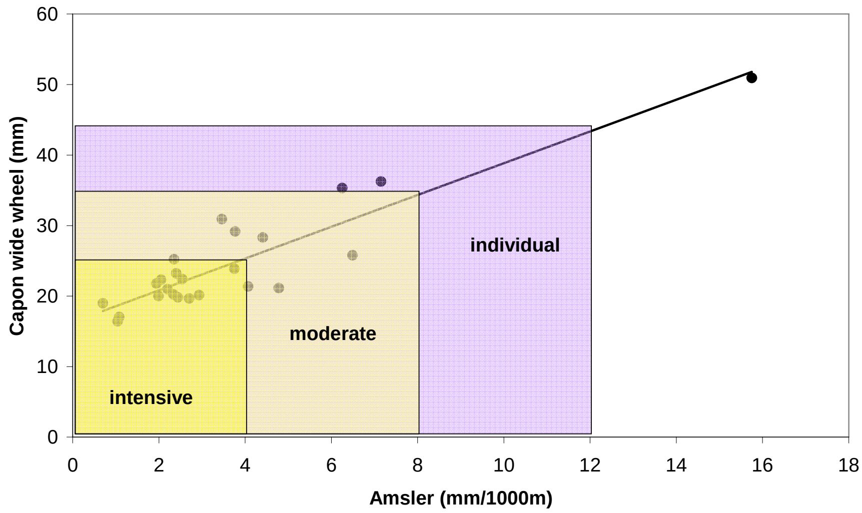


Figure 28: comparative results and related categories obtained by BBRI between the Capon wide wheel and the Amsler method

Although the surface finish of a floor covering is a personal choice, there are some recommendations to be madxe. The polished finish is not recommended to use for floor coverings intended for frequent passage, like in buildings for common use (moderate and intensive, cfr. *table 11*) unless they are made of durable granite. Even for private houses it is favourable not using polished stone units in areas that are accessible from the outside. The reason for these recommendations is that a polished finishing turns rapidly matt in these areas where there is a frequent passage, so that after a certain time the difference between the passable and impassable becomes visible. (*Figure 29*).

Figure 29: In frequently passable zones, evolution to a lighter color of the surface of blue stone floor that was initially polished

In addition, it is not recommended to mix polished and honed surfaces in the same floor. After a while, the polished one will become matt and it is not possible to polish only some of the tiles. The entire floor has to be done.

The three abrasion tests detailed above do not allow evaluation of the durability of a surface finishing. For that, specific surface abrasion tests, like the PEI-test (EN ISO 10545-7) are needed. This test was originally developed to test the wear resistance of glazed ceramic tiles. On the apparatus a number of tiles are attached, and on top of the stone a reservoir containing water and standardized little balls (with different sizes) is placed. The apparatus makes a number of rotations (combined with vibrations) to simulated a certain degree of wear. (*Figure 30*). The result of abrasion with this equipment resembles better that of the actual wear.

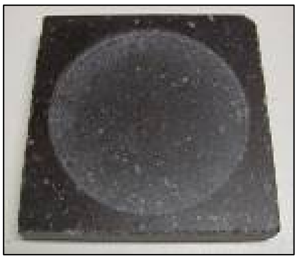


Figure 30: Change of the aspect of the surface of an originally polished blue stone, after 200 rotations during the PEI-test

6.3.3 Resistance to thermal shock

Thermal shock refers to the stress that a stone tile undergoes when it is subjected to abrupt changes in temperature. This can be the case inside, as well as outside. Stone tiles that are placed inside can come in contact with cold and hot substances such as boiling liquid or a hot saucepan. Outside a rapid change in temperature, for example sun followed by rain, can cause damage to stones. Damage is often observed by cladding on a south orientated wall.

When a natural stone is heated (can be already at 40 °C) all the composing minerals will expand in relation with their thermal expansion coefficient. If then for one reason or the other, the temperature rapidly drops, the outer minerals will shrink. Depending on the thermal conductivity of the stone and the dimensions of the unit, a stress will be caused between the inner expanded hot body and the outer shrunk cold shell. This phenomenon may result in flaking of the stone. When the stone is not homogenous in mineral composition of structures, cracks may appear between these different features. (*Figure 20*)

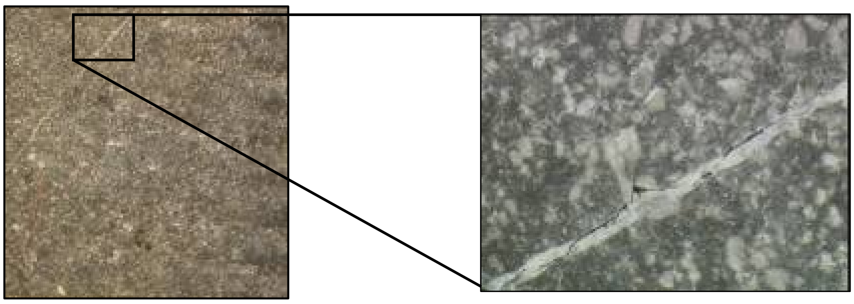


Figure 31: Crack along a calcite vein in a blue stone after a thermal shock

6.3.3.1 The influenting parameters which define different categories of use

The most important parameter (stone placed outside) is the climate. Most dangerous are the climates with rapid changes in temperature, combined with rain.

Also the application of the natural stone can play a role (from the highest to the lowest):

exterior
- paving and flooring
- solid masonry units
- wall cladding units

interior
- kitchen tops
- tablets
- flooring

6.3.3.2 Tests

Reference: EN 14066
Test: After drying to a constant mass, the samples undergo 20 successive cycles of drying at 105 ± 5 °C followed by immersion in water at 20 ± 5 °C. Before and after this test the dynamic elastic modulus is measured, to determine a change in intern structure.

6.3.3.3 Recommendations for use

When the difference of the value of the dynamic elastic modulus before and after the thermal shock test is more than 30 %, it is not recommended to use the natural stone in case where there is a risk of rapid, major temperature changes.

Note 1: The thermal shock test is under review and the relevance of it's original purpose is questioned. It may appear to be better suited for evaluation of rusting potential, see section 6.4.2.1.

Note 2: In relation to changes due to thermal influence it is worth mentioning the potential risk of bowing, an associated strength loss of marble cladding. The process is one of differential thermal and moisture induced expansion which leads to granular disaggregation and in some cases to bowing/warping. Testing for both of these matters have been developed within the EC financed project TEAM (contract no. TEAM G5RD-CT 2000-00233). The test stimulates the moisture gradient developed in the cladding and also one sided heating up to 80 °C in 25 or 50 cycles. Note that this temperature is reached on the surface of a "black reference" (figure 32). The temperature of the stone itself depends mainly on its colour. A typical white Carrara marble will reach ca 55 – 60 °C.

The "TEAM-test" is now a new work item of TC 246 and will be submitted for enquiry in 2009.

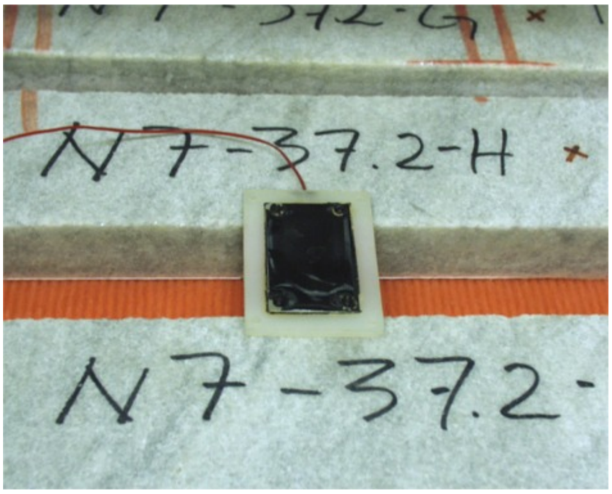


Figure 32: Black reference plate (according to ISO 4892-1) for T-measurements. Note the location between two specimens!

6.4 Application documents

In order to facilitate a proper selection of suitable stone types for different applications, concrete guidelines supporting a set of complete requirements documents have been developed for each of the most commonly used applications (enclosure 2).

It is essential that clear requirements exists and are easily accessible if they are going to be used. Such documents have to relate to existing European standards in order to be generally acceptable. However, the use of "Best available practice" is always allowed in individual construction projects and it is there we have the possibility to make significant improvements in the usage and influence the next generation of standards. For this purpose it is very important to update and disseminate the knowledge of the best available practice. As can be seen in the developed Application documents, we have chosen to make reference to standards as well as methods developed within projects such as the I-STONE.

Application templates and information documents have been prepared for the following applications:

- Cladding
- Exterior paving
- Interior flooring
- Kerbs
- Setts
- Masonry

7 Final remarks

This report has tried to give the user a guide for a sound selection of the most relevant characteristics to be known for a proper choice of natural stone in function of its use and its environment. This is certainly not an obvious work, taking into account the large number of existing laboratory tests and the various applications of stone in construction.

The technological properties of ornamental stones must be considered basically under the aspects to evaluate their quality (i.e. performance in use and durability) and to supply data to be used in the project calculations. The here proposed specifications of limits or quality grades of stone are a common view of the authors based on their own experience and relying on various research activities on the subject including field performance evaluation, laboratory tests, and behaviour on exposure sites.

Once the user will have correctly selected the characteristics he wants to know, he can ask the provider of the furnishing for reliable values for these and it will ensure that:

- these values have been obtained with the correct test procedure
  (cf. reference of the norm on the testing report, for example)
- these values are well characteristic for the concerned type of stone
  (cf. reference name on the testing report)
- these values are still representative for the stone type (cf. date on the testing report – results older than 5 years should be considered as uncertain)

Hopefully, the declared values given by the producer/importer in the frame of the CE-marking or on specific technical documentation should fulfil these conditions.
In case of doubts, uncertainties, missing results, the user should always take the opportunity to ask for new or complementary tests.

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Enclosure 1. Recommendations for different properties to test depending on the type of application

USES \ TESTS		IDENTIFICATION						PERFORMANCE IN USE			DURABILITY		
		microstructure		physical - mechanical									
		petrographic characterization	open porosity	water absorption by capillarity	thermal expansion	compressive strength	flexural strength	slip resistance	resistance to fixing	stain sensitivity	frost resistance	abrasion resistance	resistance to thermal shock
EXTERIOR	**paving and flooring**	x	xxx	x	xx[1]	xx[2]	xx[3]	xx[4]	-	x	xxx	xxx	xx[5]
	elements in contact with the floor	x	xxx	xxx	x	x	-	-	-	x	xxx	-	xx[5]
	non-vertical part or elements sticking out of the facade	x	x	x	x	x	-	-	-	x	xxx	-	xx[5]
	solid masonry units	x	x	xx[6]	x	xx[7]	-	-	-	x	xxx	-	xx[5]
	wall cladding units	x	x	x	xx[1]	x	xxx	-	xxx	x	xxx	-	xxx
INTERIOR	**flooring**	x	xxx	x	x	x	xx[3]	xx[4]	-	x	-	xxx	-
	walling	x	x	xx[8]	x	x	x	-	xx[9]	x	-	-	-
	solid masonry units	x	x	xx[8]	x	xx[7]	-	-	-	x	-	-	-
	tablet	x	x	x	x	-	-	-	-	x	-	-	-
	kitchen tops	x	xxx	x	x	-	-	-	-	x	-	-	xxx

xxx : necessary
xx : necessary only for specific applications
x : informative
- : not relevant

[1] if subjected to high temperature changes
[2] only for paving units
[3] only for slabs
[4] depending on the finishing of the unit
[5] if subjected to high temperature changes
[6] In case of massive wall
[7] if the wall is load bearing
[8] when used in a moist environment, f.e. bathroom
[9] when mechanically fixed

Enclosure 2 Application documents

1. Cladding
2. Exterior paving
3. Interior flooring
4. Kerbs
5. Setts
6. Masonry

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name:	*best specification*	**specified by:**	
construction part:	**slabs for cladding**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 1469**

climate:	climate type:		frost-thaw cycl./yr:	
	av. temperature/yr:		precipitation /yr:	
expected exposure:	*pollution, acid rain, graffiti, …*			

stone material:	stone type: *petrographic name*		**criteria and/or examples:**
	colour: *colour - shade*		*a visual criteria for the stone if*
	texture:		*possible*
building reference:	*reference if possible*		

General requirements

general:

Tender include delivery (in several stages) of slabs and other elements. The delivery shall be in accordance with descriptions and illustrations in tender document, and with the technical and aesthetical quality described.

Tolerances shall be in accordance with EN 1469. Where tolerances are stricter than/adjusted in comparison to EN 1469, this is specified here.

The natural stone quarries shall have sufficient capacity to supply the requested stone quantities and also having the possibility to future supplies of similar quality (technical and aesthetical). A description of the stone quarries, size of quarry, present and future production capacity (m^3/year, m^2/months) shall be described.

All stone products s shall be intact without any kind of repair, gluing etc.

reference samples:

General: reference samples according to EN 1469.

A reference sample shall be an adequate number of pieces of natural stone of sufficient size to indicate the general appearance of the finished work. The dimensions of individual pieces shall be at least 0,01 m² (typical values are between 0,01 - 0,25 m²in face area but may be more), an shall indicate the range of appearance regarding colouring, the vein pattern, the physical structure and the surface finish.

mock-up:

Min. 20 m^2 mock-up of the stone fo rcladding, in actual pattern and with actual surfaces /edge processing. Several step, furniture etc, elements in real size.

other:

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Sampling, Traceability and documentation	
quarry:	*The name and address of the quarry for the traceability.* *Location of the quarry shall also be given by GPS-coordinates.*
marking - labelling:	*The following information shall be given either on the packing or on the delivery notes* a) petrographic name of the stone b) commercial name of the stone c) producers name and address d) the name and address of the quarry e) the name, number and date of the followed standard f) the declared value or the classification code g) other information e.g. chemical surface treatment

Requirements for characteristics regarding microstructure			
characteristic	**standard - method**	**acceptance criteria**	**comments**
petrographic name	EN 12407	none	report to be reviewed by the consultant
apparent density	EN 1936	none	is recommended
open porosity	EN 1936	none	is recommended

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Requirements for mechanical - physical characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
water absorption (by atm. pressure)	EN 13755	none	shall be declared upon request
water absorption (by capillarity)	EN 1925	none	shall be declared upon request no testing when open porosity < 1,0 %
water vapour permeability	EN 12524	none	shall be declared when subjected to vapour
flexural strength	EN 12372	none	shall be declared can be tested with actual surface finish

Requirements for durability characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
frost resistance	EN 12371 (12 cycles)	Visual code ≤ 3 Δflex. strength ≤ 20%	shall be declared when required or upon request
thermal shock resistance	EN 14066	Δdyn. E-mod. < 30%	shall be declared when required or upon request

Requirements for characteristics regarding performance in use			
characteristic	**standard - method**	**acceptance criteria**	**comments**
breaking load at dowel hole	EN 13364	none	shall be declared when slabs are to be mechanically fixed
staining/cleaning	none		recommended to be reviewed by consultant
reaction to fire	EN 13501-1	natural stone is class A1 and fire resistant except when containing asphalt or organic filler/patching < 1%	shall be declared no testing when containing asphalt or organic filler/patching < 1%

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Other requirements

(general) surface finishing:	
tolerances:	*According to EN 1341 or stricter*
surface protection:	
anti-graffiti protection:	YES - NO type:
anchoring system (type):	Not relevant
joint width:	
quality control:	** Samples to be used as references for the delivery production must be inspected by the client before initiation of production.* ** Control of dimensions and – tolerances and visual appearance – at production plant before shipment and supplier shall sign for this and the documentation follow the delivery/shipment.* **In case of deviations from tolerances or from agreed reference samples, the work may be stopped and requested adjusted without costs for the client. The supplier is economic responsible for any delay or additional costs that may occur due to eventual need for obtaining stone supply from another supplier.*
production control testing:	*It is the clients right to perform random sampling for control of technical properties. The client will be responsible for the cost of the sampling and testing if the technical properties are in accordance with the information given by the supplier. If the results are not in accordance with this, and this causes the need for additional sampling, these samples shall be at the expense of the supplier.*
storage / transport:	*The supplier shall be responsible for the main storage at his plant until delivery plans at the construction site.* *The supplier is obliged to hold also a storage in the district and deliver whole packages according to the clients order.* *All stone products shall be delivered according to the stage plan for the stone supply. The contractor for the installation of slabs will assist the unloading.* *Delivery control will be performed by the contractor for the installation and include check of correct amount, color and sizes. Control of tolerances is to be performed during installation of the product.*
traceability system:	YES - NO (to be reviewed by the consultant)
packaging	*Slabs shall be packed according to EN 1469, point 7 and so to avoid transport, loading and unloading damages and transportation by boat or car.* *All packages and markings shall be such that delivery receipt and –control may be performed in a straight forward way* *For slabs: shall be placed horizontally on pallets with surface processed surface facing upwards.* *Each pallet shall contain only one format size and the pallets shall be marked with waterproofed colour with information about stone type, format, surface processing and number of elements.* *(specifications also given for other elements/products)*

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS			
Product name:	....	**specified by:**	....
construction part:	**slabs for cladding**	**year:**	....
location:	....	**CE-marking:**	required: **YES**
	....		standard: **EN 1469**

climate:	climate type:	....	frost-thaw cycl./yr:	....
	av. temperature/yr:	....	precipitation /yr:	....
expected exposure:	....			
	....			

stone material:	stone type:	....	**criteria and/or examples:**
	colour:	....	....
	texture:	....	....
building reference:	....		....
	....		....

General requirements	
general:	....
reference samples:	....
mock-up:	....
other:	....

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Sampling, Traceability and documentation			
quarry:	name:		
	address:		
	GPS-coordinates:		
marking - labelling:	on packing: YES - NO	in delivery notes:	YES - NO
	a) petrographic name of the stone		YES - NO
	b) commercial name of the stone		YES - NO
	c) producers name and address		YES - NO
	d) the name and address of the quarry		YES - NO
	e) the name, number and date of the followed standard		YES - NO
	f) the declared value or the classification code		YES - NO
	g) other information e.g. chemical surface treatment		YES - NO

Requirements for characteristics regarding microstructure				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
petrographic name	EN 12407			
apparent density	EN 1936			
open porosity	EN 1936			
other:				
-				
-				

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Requirements for mechanical - physical characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
water absorption (atm.)	EN 13755			
water absorption (cap.)	EN 1936			
water vapour permeability	EN 12524			
flexural strength	EN 12372			
other:				
-				
-				

Requirements for durability characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
frost resistance	EN 12371	F0 (class 0) - F1 (class 1)		
thermal shock resistance	EN 14066			
other:				
-				
-				

Requirements for characteristics regarding performance in use				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
breaking load at dowel hole	EN 13364			
staining/cleaning	none			
reaction to fire	EN 13501-1			
other:				
-				
-				

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Other requirements			
(general) surface finishing:	....		
tolerances:	....		
surface protection:	Impregnation type/system:		....
	Other treatments:		....
anti-graffiti protection:	YES - NO	type:	....
anchoring system (type):	Not relevant		
joint width:	....		
quality control:	YES - NO		
production control testing:	YES - NO		
storage / transport:	....		
	....		
traceability system:	YES - NO (to be reviewed by the consultant)		
packaging	....		
	....		

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name:	*best specification*	**specified by:**	
construction part:	**exterior pavement**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 1341**

climate:	climate type:		frost-thaw cycl./yr:	
	av. temperature/yr:		precipitation /yr:	
expected exposure:	*Traffic (cars, busses, trucks, pedestrians or bikes etc.), water runoff, marine environment etc.*			

stone material:	stone type:	*petrographic name*	**criteria and/or examples:**
	colour:	*colour - shade*	*a visual criteria for the stone if possible*
	texture:		
building reference:	*reference if possible*		

General requirements

general:

Tender include delivery (in several stages) of slabs and other elements. The delivery shall be in accordance with descriptions and illustrations in tender document, and with the technical and aesthetical quality described.

Tolerances shall be in accordance with EN 1341. Where tolerances are stricter than/adjusted in comparison to EN 1341, this is specified here.

The natural stone quarries shall have sufficient capacity to supply the requested stone quantities and also having the possibility to future supplies of similar quality (technical and aesthetical). A description of the stone quarries, size of quarry, present and future production capacity (m3/year, m2/months) shall be described.

All stone products s shall be intact without any kind of repair, gluing etc.

reference samples:

General: reference samples according to EN 1341

Specimens for paving and furnishing elements (as described above under stone type): 17 specimens, each of size 400x400x50 mm, defining the visual range of the stone, the various surface processing techniques (dolly pointed, flamed etc.) and the kinds of chamber requested.

Pedestrian crossings and sidewalks: 6 slabs, same size and requirements as above

mock-up:

Min. 20 m^2 mock-up of the stone for paving, in actual pattern and with actual surfaces/edge processing. Several step, furniture etc, elements in real size.

other:

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Sampling, Traceability and documentation	
quarry:	*The name and address of the quarry for the traceability.* *Location of the quarry shall also be given by GPS-coordinates.*
marking - labelling:	*The following information shall be given either on the packing or on the delivery notes* a) petrographic name of the stone b) commercial name of the stone c) producers name and address d) the name and address of the quarry e) the name, number and date of the followed standard f) the declared value or the classification code g) other information e.g. chemical surface treatment

Requirements for characteristics regarding microstructure

characteristic	standard - method	acceptance criteria	comments
petrographic name	EN 12407	none	report to be reviewed by the consultant
apparent density	EN 1936	none	shall be declared
open porosity	EN 1936	none	shall be declared

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Requirements for mechanical - physical characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
water absorption (by atm. pressure)	EN 13755	none	shall be declared upon request
compressive strength	EN 1936	None	test is not required, but is recommended
flexural strength	EN 12372	minimum breaking load in accordance with EN1341: Annex B, table B.1	shall be declared can be tested with actual surface finish

Requirements for durability characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
frost resistance	EN 12371 (technical test)	Visual code ≤ 3 Δflex. strength ≤ 20%	shall be declared
abrasion resistance	EN 14517	intensive use: ≤ 24 mm moderate use: ≤ 35 mm individual use: ≤ 42 mm	shall be declared
thermal shock resistance	EN 14066	Δdyn. E-mod. < 30%	only to be declared when the floor is subject to critical temperature variations

Requirements for characteristics regarding performance in use			
characteristic	**standard - method**	**acceptance criteria**	**comments**
slip resistance	EN1341: Annex D	none	shall be declared
staining/Cleaning	none		recommended to be reviewed by consultant
tactility	visual		is recommended

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Other requirements	
(general) surface finishing:	
tolerances:	*According to EN 1341 or stricter*
surface protection:	*In general it is recommended that no surface protection is applied.*
anti-graffiti protection:	YES - NO type:
anchoring system (type):	Not relevant
joint width:	
quality control:	** Samples to be used as references for the delivery production must be inspected by the client before initiation of production.* ** Control of dimensions and – tolerances and visual appearance – at production plant before shipment and supplier shall sign for this and the documentation follow the delivery/shipment.* **In case of deviations from tolerances or from agreed reference samples, the work may be stopped and requested adjusted without costs for the client. The supplier is economic responsible for any delay or additional costs that may occur due to eventual need for obtaining stone supply from another supplier.*
production control testing:	*It is the clients right to perform random sampling for control of technical properties. The client will be responsible for the cost of the sampling and testing if the technical properties are in accordance with the information given by the supplier. If the results are not in accordance with this, and this causes the need for additional sampling, these samples shall be at the expense of the supplier.*
storage / transport:	*The supplier shall be responsible for the main storage at his plant until delivery plans at the construction site.* *The supplier is obliged to hold also a storage in the district and deliver whole packages according to the clients order.* *All stone products shall be delivered according to the stage plan for the stone supply. The contractor for the installation of slabs will assist the unloading.* *Delivery control will be performed by the contractor for the installation and include check of correct amount, color and sizes. Control of tolerances is to be performed during installation of the product.*
traceability system:	YES - NO (to be reviewed by the consultant)
packaging	*Slabs shall be packed according to EN 1341, point 7 and so to avoid transport, loading and unloading damages and transportation by boat or car.* *All packages and markings shall be such that delivery receipt and –control may be performed in a straight forward way* *For slabs: shall be placed horizontally on pallets with surface processed surface facing upwards.* *Each pallet shall contain only one format size and the pallets shall be marked with waterproofed colour with information about stone type, format, surface processing and number of elements.* *(specifications also given for other elements/products)*

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS			
Product name:		**specified by:**	
construction part:	**exterior pavement**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 1341**
climate:	climate type:	frost-thaw cycl./yr:	
	av. temperature/yr:	precipitation /yr:	
expected exposure:			
stone material:	stone type:	**criteria and/or examples:**	
	colour:		
	texture:		
building reference:			

General requirements	
general:	
reference samples:	
mock-up:	
other:	

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Sampling, Traceability and documentation				
quarry:	name:			
	address:			
	GPS-coordinates:			
marking - labelling:	on packing:	YES - NO	in delivery notes:	YES - NO
	a) petrographic name of the stone			YES - NO
	b) commercial name of the stone			YES - NO
	c) producers name and address			YES - NO
	d) the name and address of the quarry			YES - NO
	e) the name, number and date of the followed standard			YES - NO
	f) the declared value or the classification code			YES - NO
	g) other information e.g. chemical surface treatment			YES - NO

Requirements for characteristics regarding microstructure

characteristic	standard - method	average value	lower/higher expected value	standard deviation
petrographic name	EN 12407			
apparent density	EN 1936			
open porosity	EN 1936			
other: -				
-				

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Requirements for mechanical - physical characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
water absorption (atm.)	EN 13755			
compressive strength	EN 1936			
flexural strength	EN 12372			
other: -				
-				

Requirements for durability characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
frost resistance	EN 12371	F0 (class 0) - F1 (class 1)		
abrasion resistance	EN 14517			
thermal shock resist.	EN 14066			
other: -				
-				

Requirements for characteristics regarding performance in use				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
slip resistance	EN1341: Annex D			
staining/Cleaning	none			
tactility	none			
other: -				
-				

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Other requirements			
(general) surface finishing:	....		
tolerances:	....		
surface protection:	Impregnation type/system:		....
	Other treatments:		....
anti-graffiti protection:	YES - NO	type:	....
anchoring system (type):	Not relevant		
joint width:	....		
quality control:	YES - NO		
production control testing:	YES - NO		
storage / transport:	....		
	....		
traceability system:	YES - NO (to be reviewed by the consultant)		
packaging	....		
	....		

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name:	*best specification*	**specified by:**	
construction part:	**interior flooring**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 12508**

used in (room):	*Entrée, kitchen, living room, bathroom, etc.*
expected exposure:	*salt, moisture, vapour, grease, acid products, alkaline products, etc.*

stone material:	stone type:	*petrographic name*	**criteria and/or examples:**
	colour:	*colour - shade*	*a visual criteria for the stone if*
	texture:		*possible*
building reference:	*reference if possible*		

General requirements

general:

Tender include delivery (in several stages) of slabs and other elements. The delivery shall be in accordance with descriptions and illustrations in tender document, and with the technical and aesthetical quality described.

Tolerances shall be in accordance with EN 1341. Where tolerances are stricter than/adjusted in comparison to EN 1341, this is specified here.

The natural stone quarries shall have sufficient capacity to supply the requested stone quantities and also having the possibility to future supplies of similar quality (technical and aesthetical). A description of the stone quarries, size of quarry, present and future production capacity (m3/year, m2/months) shall be described.

All stone products s shall be intact without any kind of repair, gluing etc.

reference samples:

General: reference samples according to EN 1341

Specimens for paving and furnishing elements (as described above under stone type): 17 specimens, each of size 400x400x50 mm, defining the visual range of the stone, the various surface processing techniques (dolly pointed, flamed etc.) and the kinds of chamber requested.

Pedestrian crossings and sidewalks: 6 slabs, same size and requirements as above

mock-up:

Min. 20 m^2 mock-up of the stone for paving, in actual pattern and with actual surfaces/edge processing. Several step, furniture etc, elements in real size.

other:

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Sampling, Traceability and documentation

quarry:

The name and address of the quarry for the traceability.
Location of the quarry shall also be given by GPS-coordinates.

marking - labelling:

The following information shall be given either on the packing or on the delivery notes

a) petrographic name of the stone
b) commercial name of the stone
c) producers name and address
d) the name and address of the quarry
e) the name, number and date of the followed standard
f) the declared value or the classification code
g) other information e.g. chemical surface treatment

Requirements for characteristics regarding microstructure

characteristic	standard - method	acceptance criteria	comments
petrographic name	EN 12407	none	shall be declared Report to be reviewed by the consultant
apparent density	EN 1936	none	shall be declared
open porosity	EN 1936	none	shall be declared

Requirements for mechanical - physical characteristics

characteristic	standard - method	acceptance criteria	comments
water absorption (by atm. pressure)	EN 13755	none	shall be declared
water absorption (by capillarity)	EN 1925	none	shall be declared upon request no testing when open porosity < 1,0 %
water vapour permeability	EN 12524	none	shall be declared when subjected to vapour
Compressive strength	EN 1936	none	test is not required, but is recommended
Flexural strength	EN 12372	none	shall be declared can also be tested with actual surface finish

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Requirements for durability characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
frost resistance	EN 12371	Visual code ≤ 3 Δdyn. E-mod. > 30% number of frost-thaw cycles to perform depends on climate	only to be declared when floor is subject to frost-thaw cycles
abrasion resistance	EN 14517	intensive use: ≤ 24 mm moderate use: ≤ 35 mm individual use: ≤ 42 mm	shall be declared
thermal shock resistance	EN 14066	Δdyn. E-mod. < 30%	only to be declared when the floor is subject to critical temperature variations

Requirements for characteristics regarding performance in use			
characteristic	**standard - method**	**acceptance criteria**	**comments**
slip resistance	EN 13373	none	shall be declared when required or upon request when roughness of surface is < 1 mm
staining/cleaning	none		recommended to be reviewed by consultant
reaction to fire	EN 13501-1	natural stone is class A1 and fire resistant except when containing asphalt or organic filler/patching < 1%	shall be declared no testing when containing asphalt or organic filler/patching < 1%
tactility	visual		shall be declared when required or upon request

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Other requirements

(general) surface finishing:	
tolerances:	*According to EN 1341 or stricter*
surface protection:	*In general it is recommended that no surface protection is applied.*
anti-graffiti protection:	YES - NO type:
anchoring system (type):	Not relevant
joint width:	
quality control:	** Samples to be used as references for the delivery production must be inspected by the client before initiation of production.* ** Control of dimensions and – tolerances and visual appearance – at production plant before shipment and supplier shall sign for this and the documentation follow the delivery/shipment.* **In case of deviations from tolerances or from agreed reference samples, the work may be stopped and requested adjusted without costs for the client. The supplier is economic responsible for any delay or additional costs that may occur due to eventual need for obtaining stone supply from another supplier.*
production control testing:	*It is the clients right to perform random sampling for control of technical properties. The client will be responsible for the cost of the sampling and testing if the technical properties are in accordance with the information given by the supplier. If the results are not in accordance with this, and this causes the need for additional sampling, these samples shall be at the expense of the supplier.*
storage / transport:	*The supplier shall be responsible for the main storage at his plant until delivery plans at the construction site.* *The supplier is obliged to hold also a storage in the district and deliver whole packages according to the clients order.* *All stone products shall be delivered according to the stage plan for the stone supply. The contractor for the installation of slabs will assist the unloading.* *Delivery control will be performed by the contractor for the installation and include check of correct amount, color and sizes. Control of tolerances is to be performed during installation of the product.*
traceability system:	YES - NO (to be reviewed by the consultant)
packaging	*Slabs shall be packed according to EN 1341, point 7 and so to avoid transport, loading and unloading damages and transportation by boat or car.* *All packages and markings shall be such that delivery receipt and –control may be performed in a straight forward way* *For slabs: shall be placed horizontally on pallets with surface processed surface facing upwards.* *Each pallet shall contain only one format size and the pallets shall be marked with waterproofed colour with information about stone type, format, surface processing and number of elements.* *(specifications also given for other elements/products)*

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS			
Product name:		**specified by:**	
construction part:	**interior paving**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 12508**
used in (room):			
expected exposure:			
stone material:	stone type:	**criteria and/or examples:**	
	colour:		
	texture:		
building reference:			

General requirements	
general:	
reference samples:	
mock-up:	
other:	

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Sampling, Traceability and documentation			
quarry:	name:		
	address:		
	GPS-coordinates:		
marking - labelling:	on packing: YES - NO	in delivery notes:	YES - NO
	a) petrographic name of the stone		YES - NO
	b) commercial name of the stone		YES - NO
	c) producers name and address		YES - NO
	d) the name and address of the quarry		YES - NO
	e) the name, number and date of the followed standard		YES - NO
	f) the declared value or the classification code		YES - NO
	g) other information e.g. chemical surface treatment		YES - NO

Requirements for characteristics regarding microstructure

characteristic	standard - method	average value	lower/higher expected value	standard deviation
petrographic name	EN 12407 (2007)			
apparent density	EN 1936 (1999)			
open porosity	EN 1936 (1999)			
other: -				
-				

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Requirements for mechanical - physical characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
water absorption (atm.)	EN 13755			
water absorption (cap.)	EN 1925			
water vapour perm.	EN 12524			
compressive strength	EN 1936			
flexural strength	EN 12372			
other:				
-				
-				

Requirements for durability characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
frost resistance	EN 12371 (2008)			
abrasion resistance	EN 14517 (2004)			
thermal shock resistance	EN 14066			
other:				
-				
-				

Requirements for characteristics regarding performance in use				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
slip resistance	EN1341: Annex D			
staining/cleaning	none			
reaction to fire	EN 13501-1			
tactility	none			
other:				
-				
-				

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Other requirements		
(general) surface finishing:		
tolerances:		
surface protection:	Impregnation type/system:	
	Other treatments:	
anti-graffiti protection:	YES - NO	type:
anchoring system (type):	Not relevant	
joint width:		
quality control:	YES - NO	
production control testing:	YES - NO	
storage / transport:		
traceability system:	YES - NO (to be reviewed by the consultant)	
packaging		

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name:	*best specification*	**specified by:**	
construction part:	**kerbs for external paving**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 1343**

climate:	climate type:		frost-thaw cycl./yr:	
	av. temperature/yr:		precipitation /yr:	
expected exposure:	*Traffic (cars, busses, trucks, pedestrians or bikes etc.), water runoff, marine environment etc.*			

stone material:	stone type:	*petrographic name*	**criteria and/or examples:**
	colour:	*colour - shade*	*a visual criteria for the stone if possible*
	texture:		
building reference:	*reference if possible*		

General requirements

general:

Tender include delivery (in several stages) of slabs and other elements. The delivery shall be in accordance with descriptions and illustrations in tender document, and with the technical and aesthetical quality described.
Tolerances shall be in accordance with EN 1343. Where tolerances are stricter than/adjusted in comparison to EN 1343, this is specified here.
The natural stone quarries shall have sufficient capacity to supply the requested stone quantities and also having the possibility to future supplies of similar quality (technical and aesthetical). A description of the stone quarries, size of quarry, present and future production capacity (m^3/year, m^2/months) shall be described.
All stone products s shall be intact without any kind of repair, gluing etc.

reference samples:

General: reference samples according to EN 1343

A reference sample shall be a number of pieces of kerb of natural stone of sufficient size to indicate the appearance of the finished work and the approximate appearance regarding the colouring, the vein pattern, the physical structure and face finish.
The reference sample shall be provided and delivered to the customer as an indication to show specific characteristic such as glass seams, spots, holes for travertine, worm holes for marble, crystalline veins and rusty spots of the offered material.

other:

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Sampling, Traceability and documentation	
quarry:	*The name and address of the quarry for the traceability.* *Location of the quarry shall also be given by GPS-coordinates.*
marking - labelling:	*The following information shall be given either on the packing or on the delivery notes* a) petrographic name of the stone b) commercial name of the stone c) producers name and address d) the name and address of the quarry e) the name, number and date of the followed standard f) the declared value or the classification code g) other information e.g. chemical surface treatment

Requirements for characteristics regarding microstructure			
characteristic	**standard - method**	**acceptance criteria**	**comments**
petrographic name	EN 12407	none	report to be reviewed by the consultant
apparent density	EN 1936	none	shall be declared
open porosity	EN 1936	none	shall be declared

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Requirements for mechanical - physical characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
water absorption (by atm. pressure)	EN 13755	none	shall be declared when required
Flexural strength	EN 12372	minimum breaking load in accordance with EN1341: Annex B, table B.1	shall be declared can be tested with actual surface finish

Requirements for durability characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
frost resistance	EN 12371 (technical test)	Visual code ≤ 3 Δflex. strength ≤ 20%	shall be declared
abrasion resistance	EN 14517	intensive use: ≤ 24 mm moderate use: ≤ 35 mm individual use: ≤ 42 mm	shall be declared
thermal shock resistance	EN 14066	Δdyn. E-mod. < 30%	only to be declared when the floor is subject to critical temperature variations

Requirements for characteristics regarding performance in use			
characteristic	**standard - method**	**acceptance criteria**	**comments**
slip resistance	EN1341: Annex D	none	shall be declared
staining/cleaning	none		recommended to be reviewed by consultant
tactility	visual		is recommended

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Other requirements	
(general) surface finishing:	
tolerances:	*According to EN 1343 or stricter*
surface protection:	*In general it is recommended that no surface protection is applied.*
anti-graffiti protection:	YES - NO type:
anchoring system (type):	Not relevant
joint width:	
quality control:	** Samples to be used as references for the delivery production must be inspected by the client before initiation of production.* ** Control of dimensions and – tolerances and visual appearance – at production plant before shipment and supplier shall sign for this and the documentation follow the delivery/shipment.* **In case of deviations from tolerances or from agreed reference samples, the work may be stopped and requested adjusted without costs for the client. The supplier is economic responsible for any delay or additional costs that may occur due to eventual need for obtaining stone supply from another supplier.*
production control testing:	*It is the clients right to perform random sampling for control of technical properties. The client will be responsible for the cost of the sampling and testing if the technical properties are in accordance with the information given by the supplier. If the results are not in accordance with this, and this causes the need for additional sampling, these samples shall be at the expense of the supplier.*
storage / transport:	*The supplier shall be responsible for the main storage at his plant until delivery plans at the construction site.* *The supplier is obliged to hold also a storage in the district and deliver whole packages according to the clients order.* *All stone products shall be delivered according to the stage plan for the stone supply. The contractor for the installation of slabs will assist the unloading.* *Delivery control will be performed by the contractor for the installation and include check of correct amount, color and sizes. Control of tolerances is to be performed during installation of the product.*
traceability system:	YES - NO (to be reviewed by the consultant)
packaging	*Slabs shall be packed according to EN 1343, point 7 and so to avoid transport, loading and unloading damages and transportation by boat or car.* *All packages and markings shall be such that delivery receipt and –control may be performed in a straight forward way* *Each pallet shall contain only one format size and the pallets shall be marked with waterproofed colour with information about stone type, format, surface processing and number of elements.* *(specifications also given for other elements/products)*

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS			
Product name:		**specified by:**	
construction part:	**kerbs for external paving**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 1343**

climate:	climate type:		frost-thaw cycl./yr:
	av. temperature/yr:		precipitation /yr:
expected exposure:			

stone material:	stone type:		**criteria and/or examples:**
	colour:		
	texture:		
building reference:			

General requirements

general:

reference samples:

other:

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Sampling, Traceability and documentation			
quarry:	name:		
	address:		
	GPS-coordinates:		
marking - labelling:	on packing: YES - NO	in delivery notes:	YES - NO
	a) petrographic name of the stone		YES - NO
	b) commercial name of the stone		YES - NO
	c) producers name and address		YES - NO
	d) the name and address of the quarry		YES - NO
	e) the name, number and date of the followed standard		YES - NO
	f) the declared value or the classification code		YES - NO
	g) other information e.g. chemical surface treatment		YES - NO

Requirements for characteristics regarding microstructure

characteristic	standard - method	average value	lower/higher expected value	standard deviation
petrographic name	EN 12407			
apparent density	EN 1936			
open porosity	EN 1936			
other: -				
-				

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Requirements for mechanical - physical characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
water absorption (atm.)	EN 13755			
flexural strength	EN 12372			
other:				
-				
-				

Requirements for durability characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
frost resistance	EN 12371	F0 (class 0) - F1 (class 1)		
abrasion resistance	EN 14517			
thermal shock resistance	EN 14066			
other:				
-				
-				

Requirements for characteristics regarding performance in use				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
slip resistance	EN 14231			
staining/Cleaning	none			
tactility	none			
other:				
-				
-				

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Other requirements		
(general) surface finishing:	....	
tolerances:	....	
surface protection:	Impregnation type/system:	....
	Other treatments:	....
anti-graffiti protection:	YES - NO type:	....
anchoring system (type):	Not relevant	
joint width:	....	
quality control:	YES - NO	
production control testing:	YES - NO	
storage / transport:	....	
	....	
traceability system:	YES - NO (to be reviewed by the consultant)	
packaging	....	
	....	

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name: *best specification* **specified by:** ____

construction part: **setts for external pavement** **year:** ____

location: ____ **CE-marking:** required: **YES**

standard: **EN 1342**

climate: climate type: ____ frost-thaw cycl./yr: ____

av. temperature/yr: ____ precipitation /yr: ____

expected exposure: *Traffic (cars, busses, trucks, pedestrians or bikes etc.), water runoff, marine environment etc.*

stone material: stone type: *petrographic name*

colour: *colour - shade*

texture: ____

criteria and/or examples: *a visual criteria for the stone if possible*

building reference: *reference if possible*

General requirements

general:

Tender include delivery (in several stages) of slabs and other elements. The delivery shall be in accordance with descriptions and illustrations in tender document, and with the technical and aesthetical quality described.

Tolerances shall be in accordance with EN 1342. Where tolerances are stricter than/adjusted in comparison to EN 1342, this is specified here.

The natural stone quarries shall have sufficient capacity to supply the requested stone quantities and also having the possibility to future supplies of similar quality (technical and aesthetical). A description of the stone quarries, size of quarry, present and future production capacity (m^3/year, m^2/months) shall be described.

All stone products s shall be intact without any kind of repair, gluing etc.

reference samples:

General: reference samples according to EN 1342.

A reference sample shall be a number of setts of natural stone of sufficient size to indicate the appearance of the finished work and the approximate appearance regarding the colouring, the vein pattern, the physical structure and face finish.
The reference sample shall be provided and delivered to the customer as an indication to show specific characteristic such as glass seams, spots, holes for travertine, worm holes for marble, crystalline veins and rusty spots of the offered material.

mock-up:

Min. 20 m^2 mock-up of the setts for paving, in actual pattern and with actual surfaces/edge processing. Several step, furniture etc, elements in real size.

other: ____

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Sampling, Traceability and documentation	
quarry:	*The name and address of the quarry for the traceability.* *Location of the quarry shall also be given by GPS-coordinates.*
marking - labelling:	*The following information shall be given either on the packing or on the delivery notes* a) petrographic name of the stone b) commercial name of the stone c) producers name and address d) the name and address of the quarry e) the name, number and date of the followed standard f) the declared value or the classification code g) other information e.g. chemical surface treatment

Requirements for characteristics regarding microstructure

characteristic	standard - method	acceptance criteria	comments
petrographic name	EN 12407	none	report to be reviewed by the consultant
apparent density	EN 1936	none	shall be declared
open porosity	EN 1936	none	shall be declared

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Requirements for mechanical - physical characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
water absorption (by atm. pressure)	EN 13755	none	shall be declared when required
Compressive strength	EN 1936	None	shall be declared

Requirements for durability characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
frost resistance	EN 12371 (technical test)	Visual code ≤ 3 Δcomp. strength ≤ 20%	shall be declared
abrasion resistance	EN 14517 (EN 1342: annex B)	intensive use: ≤ 24 mm moderate use: ≤ 35 mm individual use: ≤ 42 mm	shall be declared
thermal shock resistance	EN 14066	Δdyn. E-mod. < 30%	only to be declared when the floor is subject to critical temperature variations

Requirements for characteristics regarding performance in use			
characteristic	**standard - method**	**acceptance criteria**	**comments**
slip resistance	EN1342: Annex C	none	shall be declared
staining/Cleaning	none		recommended to be reviewed by consultant
tactility	visual		is recommended

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Other requirements

(general) surface finishing:

tolerances: *According to EN 1342 or stricter*

surface protection: *In general it is recommended that no surface protection is applied.*

anti-graffiti protection: YES - NO type:

anchoring system (type): Not relevant

joint width:

quality control:
- Samples to be used as references for the delivery production must be inspected by the client before initiation of production.
- Control of dimensions and – tolerances and visual appearance – at production plant before shipment and supplier shall sign for this and the documentation follow the delivery/shipment.
- In case of deviations from tolerances or from agreed reference samples, the work may be stopped and requested adjusted without costs for the client. The supplier is economic responsible for any delay or additional costs that may occur due to eventual need for obtaining stone supply from another supplier.

production control testing:
It is the clients right to perform random sampling for control of technical properties. The client will be responsible for the cost of the sampling and testing if the technical properties are in accordance with the information given by the supplier. If the results are not in accordance with this, and this causes the need for additional sampling, these samples shall be at the expense of the supplier.

storage / transport:
The supplier shall be responsible for the main storage at his plant until delivery plans at the construction site.
The supplier is obliged to hold also a storage in the district and deliver whole packages according to the clients order.
All stone products shall be delivered according to the stage plan for the stone supply. The contractor for the installation of slabs will assist the unloading.
Delivery control will be performed by the contractor for the installation and include check of correct amount, color and sizes. Control of tolerances is to be performed during installation of the product.

traceability system: YES - NO (to be reviewed by the consultant)

packaging
Slabs shall be packed according to EN 1342, point 7 and so to avoid transport, loading and unloading damages and transportation by boat or car.
All packages and markings shall be such that delivery receipt and –control may be performed in a straight forward way
For slabs: shall be placed horizontally on pallets with surface processed surface facing upwards.
Each pallet shall contain only one format size and the pallets shall be marked with waterproofed colour with information about stone type, format, surface processing and number of elements.
(specifications also given for other elements/products)

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name:		**specified by:**	
construction part:	**setts for external pavement**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 1342**

climate:	climate type:		frost-thaw cycl./yr:	
	av. temperature/yr:		precipitation /yr:	
expected exposure:				

stone material:	stone type:		**criteria and/or examples:**
	colour:		
	texture:		
building reference:			

General requirements

general:

reference samples:

mock-up:

other:

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Sampling, Traceability and documentation			
quarry:	name:		
	address:		
	GPS-coordinates:		
marking - labelling:	on packing: YES - NO	in delivery notes:	YES - NO
	a) petrographic name of the stone		YES - NO
	b) commercial name of the stone		YES - NO
	c) producers name and address		YES - NO
	d) the name and address of the quarry		YES - NO
	e) the name, number and date of the followed standard		YES - NO
	f) the declared value or the classification code		YES - NO
	g) other information e.g. chemical surface treatment		YES - NO

Requirements for characteristics regarding microstructure

characteristic	standard - method	average value	lower/higher expected value	standard deviation
petrographic name	EN 12407			
apparent density	EN 1936			
open porosity	EN 1936			
other:				
-				
-				

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Requirements for mechanical - physical characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
water absorption (atm.)	EN 13755			
compressive strength	EN 1936			
other:				
-				
-				

Requirements for durability characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
frost resistance	EN 12371	F0 (class 0) - F1 (class 1)		
abrasion resistance	EN 14517			
thermal shock resist.	EN 14066			
other:				
-				
-				

Requirements for characteristics regarding performance in use				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
slip resistance	EN1341: Annex D			
staining/Cleaning	none			
tactility	none			
other:				
-				
-				

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Other requirements			
(general) surface finishing:	....		
tolerances:	....		
surface protection:	Impregnation type/system:		....
	Other treatments:		....
anti-graffiti protection:	YES - NO	type:	....
anchoring system (type):	Not relevant		
joint width:	....		
quality control:	YES - NO		
production control testing:	YES - NO		
storage / transport:	....		
	....		
traceability system:	YES - NO (to be reviewed by the consultant)		
packaging	....		
	....		

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS

Product name:	*best specification*	**specified by:**	
construction part:	**masonry units**	**year:**	
location:		**CE-marking:**	required: **YES**
			standard: **EN 771-6**

climate:	climate type:		frost-thaw cycl./yr:	
	av. temperature/yr:		precipitation /yr:	
expected exposure:	*marine environment, acid rain, pollution, graffiti etc.*			

stone material:	stone type:	*petrographic name*	**criteria and/or examples:**
	colour:	*colour - shade*	*a visual criteria for the stone if*
	texture:		*possible*
building reference:	*reference if possible*		

General requirements

general:

Tender include delivery (in several stages) of slabs and other elements. The delivery shall be in accordance with descriptions and illustrations in tender document, and with the technical and aesthetical quality described.

Tolerances shall be in accordance with EN 771-6. Where tolerances are stricter than/adjusted in comparison to EN 771-6, this is specified here.

The natural stone quarries shall have sufficient capacity to supply the requested stone quantities and also having the possibility to future supplies of similar quality (technical and aesthetical). A description of the stone quarries, size of quarry, present and future production capacity (m3/year, m2/months) shall be described.

All stone products s shall be intact without any kind of repair, gluing etc.

reference samples:

General: reference samples according to EN 771-6 (5.4.2)

A reference sample shall be a number of pieces of kerb of natural stone of sufficient size to indicate the appearance of the finished work and the approximate appearance regarding the colouring, the vein pattern, the physical structure and face finish.
The reference sample shall be provided and delivered to the customer as an indication to show specific characteristic such as glass seams, spots, holes for travertine, worm holes for marble, crystalline veins and rusty spots of the offered material.

mock-up:

Min. 20 m^2 mock-up of the stone for masonry, in actual pattern and with actual surfaces/edge processing. Several step, furniture etc, elements in real size.

other:

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Sampling, Traceability and documentation	
quarry:	*The name and address of the quarry for the traceability.* *Location of the quarry shall also be given by GPS-coordinates.*
marking - labelling:	*The following information shall be given either on the packing or on the delivery notes* a) petrographic name of the stone b) commercial name of the stone c) producers name and address d) the name and address of the quarry e) the name, number and date of the followed standard f) the declared value or the classification code g) other information e.g. chemical surface treatment

Requirements for characteristics regarding microstructure			
characteristic	**standard - method**	**acceptance criteria**	**comments**
petrographic name	EN 12407	none	report to be reviewed by the consultant
apparent density	EN 1936	none	shall be declared
open porosity	EN 1936	none	shall be declared

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Requirements for mechanical - physical characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
water absorption (by capillarity)	EN 772-1	none	shall be declared
water vapour permeability	EN 12524	none	shall be declared when subjected to vapour
compressive strength	EN 772-1 (annex A)	none	shall be declared
flexural strength	EN 12372	none	shall be declared

Requirements for durability characteristics			
characteristic	**standard - method**	**acceptance criteria**	**comments**
frost resistance	EN 12371 (technical test)	Visual code ≤ 3 Δflex. strength $\leq 20\%$	shall be declared
thermal shock resistance	EN 14066	Δdyn. E-mod. $< 30\%$	only to be declared when the floor is subject to critical temperature variations

Requirements for characteristics regarding performance in use			
characteristic	**standard - method**	**acceptance criteria**	**comments**
staining/cleaning	none		recommended to be reviewed by consultant
reaction to fire	EN 13501-1	natural stone is class A1 and fire resistant except when containing asphalt or organic filler/patching $< 1\%$	shall be declared no testing when containing asphalt or organic filler/patching $< 1\%$

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Other requirements	
(general) surface finishing:	
tolerances:	*According to EN 771-6 or stricter*
surface protection:	*In general it is recommended that no surface protection is applied.*
anti-graffiti protection:	YES - NO type:
anchoring system (type):	Not relevant
joint width:	
quality control:	** Samples to be used as references for the delivery production must be inspected by the client before initiation of production.* ** Control of dimensions and – tolerances and visual appearance – at production plant before shipment and supplier shall sign for this and the documentation follow the delivery/shipment.* **In case of deviations from tolerances or from agreed reference samples, the work may be stopped and requested adjusted without costs for the client. The supplier is economic responsible for any delay or additional costs that may occur due to eventual need for obtaining stone supply from another supplier.*
production control testing:	*It is the clients right to perform random sampling for control of technical properties. The client will be responsible for the cost of the sampling and testing if the technical properties are in accordance with the information given by the supplier. If the results are not in accordance with this, and this causes the need for additional sampling, these samples shall be at the expense of the supplier.*
storage / transport:	*The supplier shall be responsible for the main storage at his plant until delivery plans at the construction site.* *The supplier is obliged to hold also a storage in the district and deliver whole packages according to the clients order.* *All stone products shall be delivered according to the stage plan for the stone supply. The contractor for the installation of slabs will assist the unloading.* *Delivery control will be performed by the contractor for the installation and include check of correct amount, color and sizes. Control of tolerances is to be performed during installation of the product.*
traceability system:	YES - NO (to be reviewed by the consultant)
packaging	*Slabs shall be packed according to EN 1341, point 7 and so to avoid transport, loading and unloading damages and transportation by boat or car.* *All packages and markings shall be such that delivery receipt and –control may be performed in a straight forward way* *For slabs: shall be placed horizontally on pallets with surface processed surface facing upwards.* *Each pallet shall contain only one format size and the pallets shall be marked with waterproofed colour with information about stone type, format, surface processing and number of elements.* *(specifications also given for other elements/products)*

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SPECIFICATIONS FOR NATURAL STONE PRODUCTS				
Product name:		**specified by:**		
construction part:	**masonry units**	**year:**		
location:		**CE-marking:**	required:	**YES**
			standard:	**EN 771-6**
climate:	climate type:		frost-thaw cycl./yr:	
	av. temperature/yr:		precipitation /yr:	
expected exposure:				
stone material:	stone type:		**criteria and/or examples:**	
	colour:			
	texture:			
building reference:				

General requirements	
general:	
reference samples:	
mock-up:	
other:	

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Sampling, Traceability and documentation				
quarry:	name:	....		
	address:	....		
		....		
	GPS-coordinates:	....		
marking - labelling:	on packing:	YES - NO	in delivery notes:	YES - NO
	a) petrographic name of the stone			YES - NO
	b) commercial name of the stone			YES - NO
	c) producers name and address			YES - NO
	d) the name and address of the quarry			YES - NO
	e) the name, number and date of the followed standard			YES - NO
	f) the declared value or the classification code			YES - NO
	g) other information e.g. chemical surface treatment			YES - NO

Requirements for characteristics regarding microstructure				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
petrographic name	EN 12407			
apparent density	EN 1936			
open porosity	EN 1936			
other:				
-				
-				

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Requirements for mechanical - physical characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
water absorption (cap.)	EN 772-1			
water vapour permeability	EN 12524			
compressive strength	EN 772-1 (annex A)			
flexural strength	EN 12372			
other:				
-				
-				

Requirements for durability characteristics				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
frost resistance	EN 12371	F0 (class 0) - F1 (class 1)		
thermal shock resistance	EN 14066			
other:				
-				
-				

Requirements for characteristics regarding performance in use				
characteristic	**standard - method**	**average value**	**lower/higher expected value**	**standard deviation**
staining/cleaning	none			
reaction to fire	EN 13501-1			
other:				
-				
-				

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Other requirements		
(general) surface finishing:	....	
tolerances:	....	
surface protection:	Impregnation type/system:	....
	Other treatments:	....
anti-graffiti protection:	YES - NO	type: ....
anchoring system (type):	Not relevant	
joint width:	....	
quality control:	YES - NO	
production control testing:	YES - NO	
storage / transport:	....	
	....	
traceability system:	YES - NO (to be reviewed by the consultant)	
packaging	....	
	....	