BKSTONE

QUARRYING & MANAGEMENT

BKSTONE- Higher Education-Enterprise Platform for Fostering Modernization and Sustainable Growth in Natural Stone Industry in Western Balkans

610483-EPP-1-2019-1-AL-EPPKA2-CBHE-JP

Co-funded by the Erasmus+ Programme of the European Union

Themes

Higher Education–Enterprise platform for fostering, modernisation and sustainable growth in natural stone industry in Western Balkans Project acronym: BKSTONE.
Programme: Erasmus+.
Key Action: Cooperation for innovation and the exchange of good practices.
Action: Capacity Building in Higher Education.
Action Type: Joint Projects.
Project website: https://bkstoneproject.com/
Lead partner organisation: Universiteti Politeknik i Tiranës, Tirana, Albania.
Project manager: Prof. dr. Alma Afezolli

Quarrying is one of the most important stages in the production of ornamental and dimension stones as many critical parameters concerning the cost and the quality of the final stone product and defined at this stage. Moreover, due to the huge quantities extracted material and the big amounts of the waste material produced it is necessary to exploit the store reserves in a reasonable way in order to avoid the various environmental problems that may be encountered. On the other hand, quarrying is a very difficult task including a lot of uncertain factors and in this respect stability and thus safe operation of the quarries is of at most importance.

Therefore, specifically, this eBook is focused on a deep knowledge of new innovative solution of 4.0 Industry as well as traditional solutions applied to Stone sector in main four areas: quarrying, manufacturing, management and circular economy. To achieve the objective of sustainable development in a Circular Mining industry, societies need to develop a series of tools that are undoubtedly the product of research, development and human adaptation to the environment. In this eBook sustainable processes in the natural stone industry are known and studied, understood as those that consume less raw materials, energy and produce less waste, thus producing less impact on the environment and preserving economic resources.

Mining & Quarriyng

Exploration methods and ore reserve estimation

Stone quarrying methods and technologies used

Health and safety in quarrying and proccesing operations

The morphological and geological variability of stone deposits and the natural differentiation of the material's physical characteristics, from one site to another, is the reason for the huge spectrum of quarry types that can be found, even within the same geographical area. As a result, there is an extremely wide range of technical solutions developed and adopted for stone quarrying, which often reflect traditions and experiences matured in specific situations.

In the last years, evolution and adaptation of new quarrying technologies has been considerable, even if today, still some "underdeveloped" situations exist next to fully mechanized quarries, where the lack of technical development not only does affect productivity, but it has severe impacts on the environment, large quantities of waste and creates insufficient safety conditions. For these reasons, an eBook covering all these topics in mining applied to natural stone is really necessary.

Health protection is also a key issue in the natural stone sector. Due to the need of handling big masses of rock, the use of the heavy and dangerous machinery and explosives and the continuous production of dust, the quarrying and manufacturing of the stone must be done following very specific procedures to reduce to the minimum the risks of accidents and health problems. In EU these procedures have been deeply developed during the last decades, due the increasing importance giving to this issue.

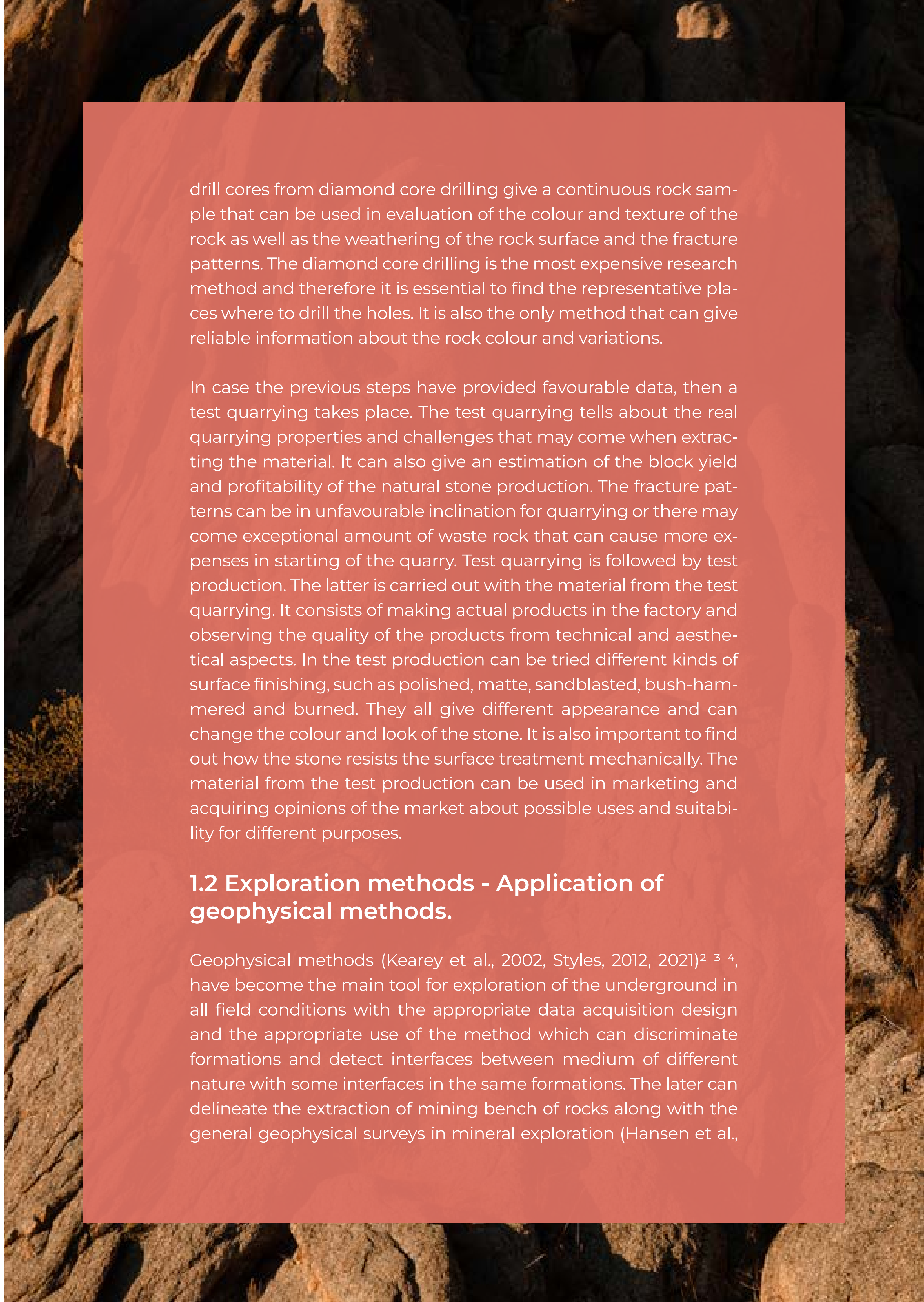
Exploration methods and ore reserve estimation

1.1 Important aspects in the evaluation of natural stone deposits.

Natural stone exploration is closely linked to geological mapping and its methods as the same systematic and geological observation procedures are used in both. Natural stone deposit exploration differs from conventional bedrock mapping by concentrating on some aspects that are seldom observed in bedrock mapping, such as the amount of fractures and joints, fracture systems as well as homogeneity and colour of the rock[1] The first step is to study the geology of a certain area. The modern geological mapping data allows getting quite accurate view of the geology of a certain region, which helps in choosing the most interesting areas where to focus the field work. The topographic data can reveal geological orientations and large structures in areas where the soil cover is not too thick and some parts of the bedrock are exposed.

The following step is performed on the field. Normal bedrock observations are carried out in the prospecting of new natural stone occurrences and deposits. The work is mainly mapping and evaluation of the bedrock outcrops and producing a total picture of the geological environment to point out the most homogeneous and un-fractured areas. Conventional elements of the mapping including bedrock data, texture and structure data and the tectonic evaluation of the area are used for making the total evaluation. When the promising areas and occurrences have been found the bedrock surface is usually exposed either by hand work or by a machine, such as an excavator. The exposed outcrops are mapped in detail for the joints and fractures of different dimension. The observations of the fractures can be mapped with a paper map and compass or by measuring the fracture orientation by GPS equipment (starting point, middle points, ending point). The colour, homogeneity and texture are first observed from the exposed outcrops.

Next, drill cores are extracted in order to further study the material. The drill cores from diamond core drilling give a continuous rock sample that can be used in evaluation of the colour and texture of the rock as well as the weathering of the rock surface and the fracture patterns. The diamond core drilling is the most expensive research method and therefore it is essential to find the representative places where to drill the holes. It is also the only method that can give reliable information about the rock colour and variations.



In case the previous steps have provided favourable data, then a test quarrying takes place. The test quarrying tells about the real quarrying properties and challenges that may come when extracting the material. It can also give an estimation of the block yield and profitability of the natural stone production. The fracture patterns can be in unfavourable inclination for quarrying or there may come exceptional amount of waste rock that can cause more expenses in starting of the quarry. Test quarrying is followed by test production. The latter is carried out with the material from the test quarrying. It consists of making actual products in the factory and observing the quality of the products from technical and aesthetical aspects. In the test production can be tried different kinds of surface finishing, such as polished, matte, sandblasted, bush-hammered and burned. They all give different appearance and can change the colour and look of the stone. It is also important to find out how the stone resists the surface treatment mechanically. The material from the test production can be used in marketing and acquiring opinions of the market about possible uses and suitability for different purposes.

1.2 Exploration methods - Application of geophysical methods.

Geophysical methods (Kearey et al., 2002, Styles, 2012, 2021)[2,3,4], have become the main tool for exploration of the underground in all field conditions with the appropriate data acquisition design and the appropriate use of the method which can discriminate formations and detect interfaces between medium of different nature with some interfaces in the same formations. The later can delineate the extraction of mining bench of rocks along with the general geophysical surveys in mineral exploration (Hansen et al., 1967, Dentith and Mudge, 2014, Johnson, 2020)[5] [6] [7].

The general procedure in exploration surveys is starting with reconnaissance geophysical methods (gravity, magnetics, geoelectrics with soundings) in order to detect in a regional mode the general geological structure and outline the area of interest. In the case of marbles, they are characterized by resistivity highs (resistivity >2000 Ohm.m in respect of schist 750 Ohm.m), a modest reduction in magnetic field intensity (magnetic susceptibility 2x10-6 emu in respect of schist 120x10-6 emu) and gravity high anomalies (density 2.73 gr/cm3 in respect of schist 2.64 gr/cm3).

The geophysical maps in the regional mode outline the area of interest for marbles exploitation with the more precise geophysical methods being the next step which will result the best design of mining activity.

The Electrical Resistivity Tomography (ERT) gives with thousands of measurements an underground very detailed geoelectrical model which in a broader manner outlines the body of marble with the higher resistivities that means more solid pure condition. Refraction seismics can also offer the same results (Fig. 1.1).

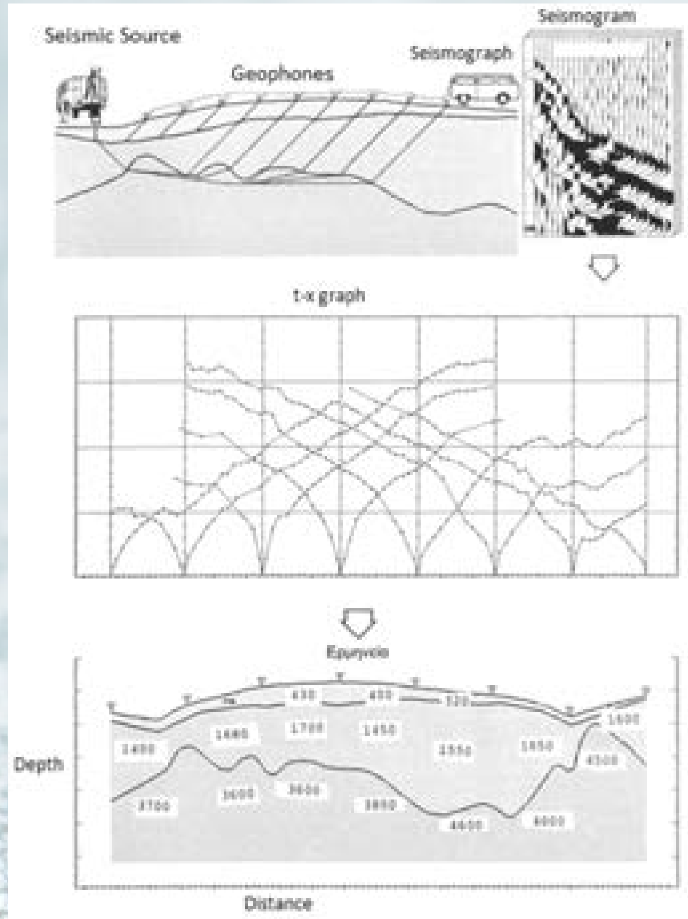


Figure 1.1. Refraction seismic setup with the seismogram giving the first seismic arrivals, which in the respective graph if it is interpreted can give seismic section with the higher velocities providing the pure solid marble body in respect with the lower velocities region of fractured or weathered rock formation under the soil top layer.

Figure 1.2. a) Overview of a quarry; (b) Details of the three perpendicular holes that delineate the secondary bank; (c) Cutting of tertiary blocks with a diamond wire (detail of the block is outlined). Excavator extracting blocks over the sand bed. Note the breakage along a fracture plane; (d) Squaring a block with a diamond wire; (e) Squaring a block with a drill and wedges along a crack; (f) Excavator with a hydraulic hammer reducing the size of the stone intended for micronized carbonate. (Martinez et al., 2017).

Diamond core drilling give a continuous rock sample that can be used in evaluation of the colour and texture of the rock as well as the weathering of the rock surface and the fracture patterns. The diamond core drilling is the most expensive research method and therefore it is essential to find the representative places where to drill the holes. It is also the only method that can give reliable information about the rock colour and variations.

In the production mode in marble quarries (Fig. 1.2), the outline of the most pure solid marble body is the first question for the mining activi-

ty to approach it. ERT and GPR geophysical methods are very useful for that (Martinez et al., 2017)[8]. The marble body can be outlined by the ERT method. Similar picture can be acquired with Ground Penetrating Radar (GPR). Its high frequency signal reflections provide better resolution of the underground model. In addition the GPR section can detect fractures in the marble body thanks to its great resolution.
The high frequency EM method of GPR provides the great resolution in the section for fracture detection and the cutting of the best quality marble body. At Thassos marble quarry Grandjean and Gourry (1996) can detect fractures using different GPR antennas (central frequency 900MHz and 300MHz) with the higher frequency one giving better results [9].

High-density spatial sampling versus antenna orientation has a great impact on 3D GPR fracture imaging (Marchesini and Grasmueck, 2015)[10]and enables the high-resolution characterization of 3D fracture networks on subsurface timeslices in near photographic quality.

The use of various antennas of different central frequency (Lualdi and Zanzi, 2003)[11] gives great detection depth with the low frequency one but lower resolution in the section compared with the higher frequency antenna section at shallow depths. The difference in resolution in the GPR sections between antennas of 25MHz, 50MHz, 100MHz central frequency is described in detail by Porsani et al. (2006)[12].

Finally in the mining works as more precise presentation of the space ahead of the excavation the greater of exploitation of the good quality marble block. Apostolopoulos et al. (2016)[13] propose ERT sections for broader inspection of the space ahead of excavation and GPR with a combination of 250MHz and 500MHz shielded antenna for precise detection of fractures in open cast or underground mining.

1.3 Computational methods for ore reserve estimation

Mineral resources are defined as the concertation of material of economic interest in earth's crust. Ore reserves are those parts of mineral resources for which grade and tonnage have been established with reasonable assurance by various techniques and can be mined profitably using current technologies. The reserve estimation is quantification of economic material present in the ore body with reasonable accuracy. It also involves computation of grade, thickness and different qualitative parameters, which are required for commercial exploitation of the ore[14].

The ore reserve estimation methods can be grouped in three ways: Geometric Method (Conventional Method), Statistical or Geostatistical Method, Computer application or software.

Several assumptions are considered for reserve estimation:

-The parameters of an ore body established at one point changes to an adjoining point in accordance with certain principle like rule of gradual changes, rule of nearest points.

-The projected continuity of ore body based on exploration data is supposed by geological setup.

-The samples are collected with equal precision at every point and they are representing the ore zone.

Conventional methods of ore reserve estimation are based on anisotropy, drilling grid pattern and stage of exploration:

-Polygonal method
-Triangular method
-Cross section method
-Inverse Distance method

For example in the cross section method, the ore body is interpreted on cross-section. The ore body is divided into different segments with the help of transverse section lines. The section line can be spaces at equal or unequal intervals based on grid interval and borehole locations.

The computation steps involved are the following:
The total ore body is divided into sub-blocks along section line and a length equal to half of the distance between the adjoining sections.
For computation of reserve, volume of each sub-block is required. The volume is calculated by multiplication of sectional area with half the distance of adjoining section on each side (i.e. area of influence).

The sectional area of ore body is calculated by geometric formula. CAD software can be used to measure area of irregular ore body.

Tonnage for each sub-block is calculated by multiplication of volume and specific gravity.
Metal content of each sub-block is calculated by multiplying tonnage and average grade of that sub-block.

Total tonnage of ore body is summation of sub-block tonnages. Similarly, total metal content is summation of sub-block metal contents.

Average grade of ore body is total metal content divided by total tonnage in percentage term.

With the advances in technology and invention of computer, software developers used their soft skill to correlate the basics of estimation procedure with some mathematical functions and equations to develop some excellent software for estimating ore reserves with higher speed and better accuracy. These software packages, however, also utilize the three basic principles of conventional methods described above. On the other hand, geostatistical tools later became a handy source in estimating an ore reserve using computer. The three usually used techniques in computer aided ore reserve estimation are: nearest neighbour, inverse distance and kriging[15,16]. The process involves the creation of a geological database from the available drillhole data. The next steps are called sectioning and digitizing. Sectioning is the process of creating a mirror image of the drillholes when cut through by a plane, and digitizing is the act of outlining the ore terrain or mineralization. These processes are carried out to create an outline file out of the mineralization, which is then used to develop a 3D model of the ore body. A 3D model of the ore body is the best resource for visualising the characteristics of the deposit (Figure 1.3).

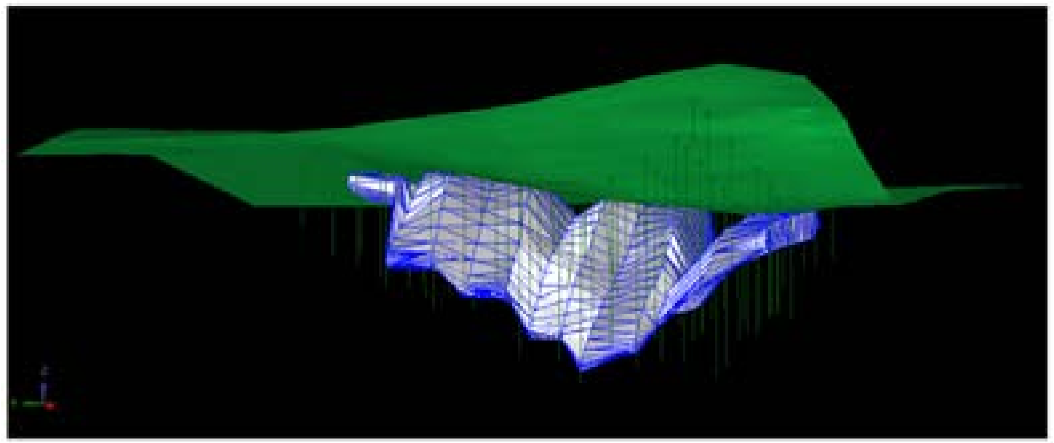


Figure 1.3. A 3D model of the orebody developed from digitized sections of the drillholes (green lines), here depicted in relation to the topography (software: Geovia Surpac)

block model is normally developed for better grade determination as the entire deposit is divided into small blocks of similar sizes. By utilizing the estimation techniques (inverse distance, kriging etc.) values are calculated for each block. In addition, the overall volume and tonnage of the entire deposit is calculated by the software [17,18].

1.4. Recovery Rate in natural stone quarries

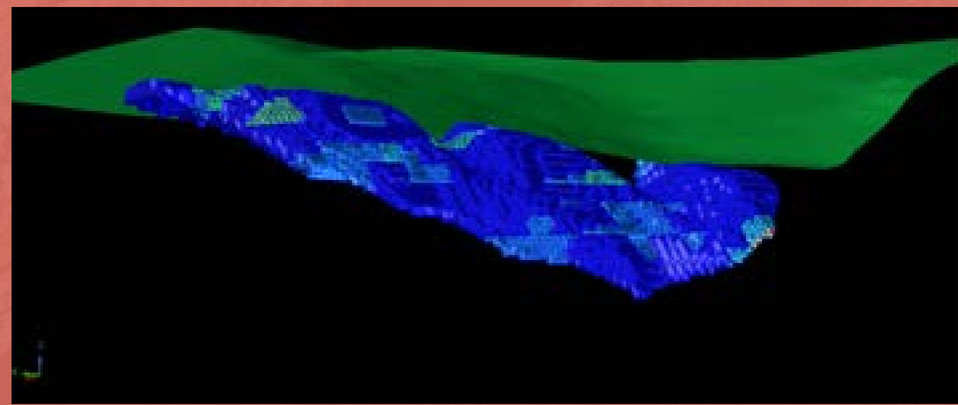


Figure 1.5. A block model of the orebody. The colours denote the differences in grade (software: Geovia Surpac).

One of the most common words used in natural stone quarries is “recovery rate”. However, the term is usually used to describe very different things. In reality, there are different concepts, which define the recovery rate. One concept would be restricting it to obtaining dimensional blocks in commercial size according to international practices. Another concept of recovery rate would, in addition, also include using waste stone (defined here as not being dimensional blocks) for gravel crushed stone for industrial purpose like for the paper industry, filters, toothpaste, etc. There is another element to recovery rate, which is, in fact, key to whether the business is feasible or not: when recovery rate is defined using economic criteria. Not all blocks have the same commercial value- the tones, the veins, the black spots all these can dramatically affect the sales price of the material once it is being commercialized.

The situation becomes even more difficult when the dimensional blocks, perfect in every other way, have fissures. A block that has fissures can completely break down when being processed in the gangsaws, block cutters or multi-wire machines. Blocks with fissures can not only have zero value, they can even have negative value, since sometimes the fissures, especially when they are small and located well inside the blocks, are identified only when the block has been processed and breaks up.
The extraction of saleable blocks is one of the most critical processes in the quarrying of dimensional stones. The quarry operators are constantly under pressure to produce good quality and required quantity of saleable blocks to meet their production target and market demand. During the process of extraction, employing the conventional and crude methods the rock mass suffers severe damage and renders the potential reserves of saleable blocks useless[19].

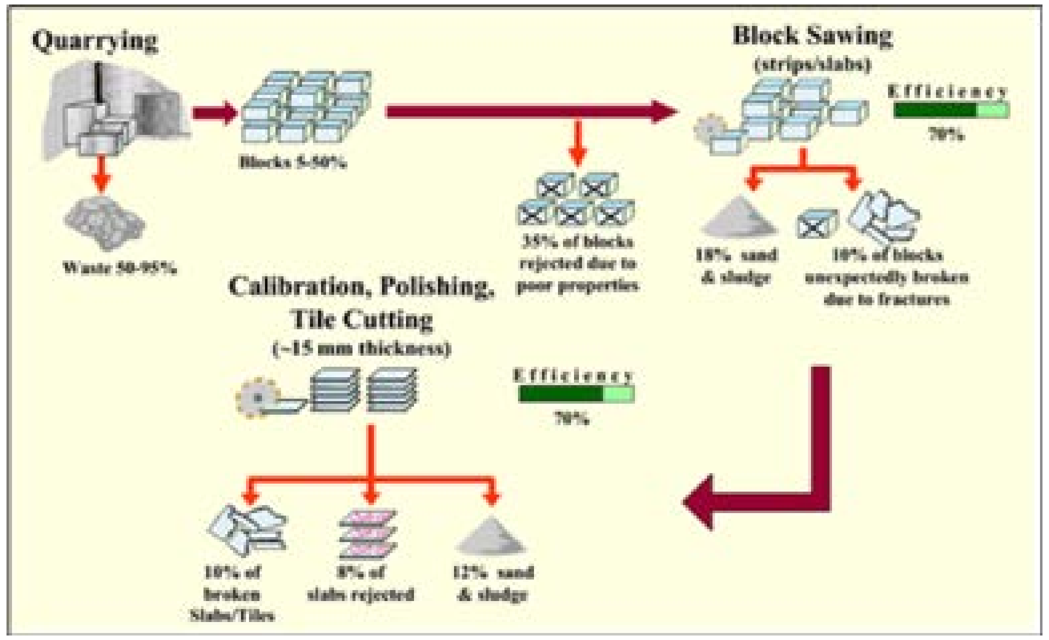


Figure 1.6. Recovery and waste generation[20]

ting method for block splitting. A major factor awfully affecting the block geometry is the inability to predict the geological and geotechnical fractures such as the jointing, bedding plane and fault systems, which control the block layout on a bench. Joint mapping is only applicable for mapping on exposed rock surfaces and it is difficult to measure the fractures within a rock mass using conventional measuring methods. The accuracy and efficiency of the drilling machines for drilling accurate blast holes are critical when explosives are used to separate a block and that makes the difference between a good and bad quarry. To design the drilling and blasting technique for a particular site, apart from formulas and calculations, some actual field trials are necessary for standardization.

In general the production from the quarry will be irregular and continuous record of low recovery and substantial damage to the rock mass poses a serious threat to the continuance of the mining operations in most of the quarries. The scientific exploitation of the given deposit is a key for improving the recovery. The average recovery percentage world over by various authors is presented in table below[21].

When the intention is to merely blast and remove stone for its physical properties, the recovery can be almost 100% of the volume removed, while when the same stone is quarried with the intention of producing dimension stone blocks, recovery of saleable blocks is typically between 3% and 30%, while the cost of removal of the material is typically of the order of 10 to 15 times the cost in the former case. This increased cost results from the techniques used to split or cut the stone without damage and the special attention that must be given to carefully extracting rectangular blocks of material from between flaws in the stone (such as cracks, joints, veins, banding or accumulations of a single mineral or colour), which render it unsuitable in terms of the market requirements, rather than just simply extracting blocks of a standard size without regard to these flaws.

Ashmole (2008)[22] explains a complicating factor as that the stone often has one or more preferential grain or cleavage directions (freeway, second/easy way, tough way) along which it splits preferentially, even when attempting to split oblique to these directions. The flaws in the material however often run oblique to the grain direction, with the result that recovery of saleable blocks is compromised. The figure below depicts a two dimensional representation of face in a granite quarry, where defects such as veins or joints cross the bench at an angle to the cutting directions of the stone (parallel to the edges of the bench) which are determined by the natural grain or cleavage of the tone. In the first case, the initial cutting is made on a standard grid of 3 m by 1.5 m, as depicted by the dotted lines, while in the second case, the initial cuts are planned in such a way as to yield an optimum recovery and size of blocks produced. The second case yields a total volume of final blocks 15% higher than the first case, but with a total value that is 43% higher due to a higher proportion of large blocks. In addition, in the second case, 88% of the production is in large block sizes, which are in greater demand in the market, compared to only 44% in the first case.

Figure 1.7. Impact of flaws and primary cutting on recovery[23]

Stone quarrying methods and technologies used

Quarrying is one of the most important stages in the production of ornamental and dimension stones as many critical parameters concerning the cost and the quality of the final stone product and defined at this stage. Moreover, due to the huge quantities extracted material and the big amounts of the waste material produced it is necessary to exploit the store reserves in a reasonable way in order to avoid the various environmental problems that may be encountered. On the other hand quarrying is a very difficult task including a lot of uncertain factors and in this respect stability and thus safe operation of the quarries is of at most importance.

The morphological and geological variability of stone deposits and the natural differentiation of the materials physical characteristics, from one site to another, is the reason for the huge spectrum of quarry types that can be found, even within the same geographical area. As a result, there is an extremely wide range of technical solutions developed and adopted for stone quarrying, which often reflect traditions and experiences matured in specific situations. In the last years, evolution and adaptation of new quarrying technologies has been considerable, even if today, still some “underdeveloped” situations exist next to fully mechanized quarries, where the lack of technical development not only does affect productivity, but it has severe impacts on the environment and creates insufficient safety conditions.

Quick technological evolution and constantly changing market orientations (in other words fashion) create a “dynamic” aspect of the stone deposit concept: in fact, the combination of the market demand for a given material with the technical possibility of economically extracting it, is able in a short time, to “transform” a simple stone deposit to a valuable reserve.

The factors that have a direct influence on the management of stone quarries are manifold and interdependent, affecting at the same time the choice of type, method and technology for the exploitation.

It is evident that the characteristics of the deposit affect the choice of the exploitation methods and technologies; the rational organization of production and, as a consequence, the mining recovery, the block yield and finally the general “performance” of the quarrying activity, depend on these factors[24].

The most important factors to be considered for rational planning and management of a quarrying activity for dimension stones are presented in Figure 1, underlining the interconnections among the different phases. Nevertheless, geo-mining exploration, exploitation and rehabilitation, processing and commercial use of the dimension stones should be viewed as one and not as several different aspects, as demonstrated in some of the most important productive activities in Europe.

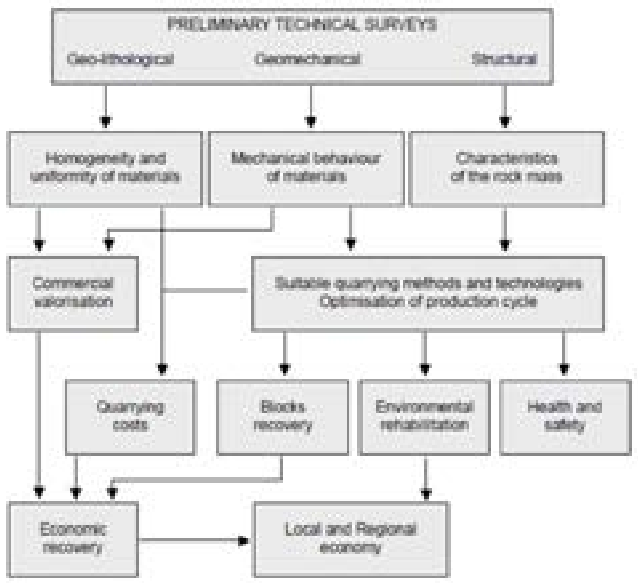


Figure 2.1. The most important factors to be considered for rational management and planning of a quarrying activity for dimension stones (Cardu and Lovera, 2004)

2.1. Exploitation methods and techniques (drilling, wire cutting, sawing, other techniques)

Dimension stones can be exploited opencast[25,26], (surface mining) or underground. Where stone deposits are near the surface with little or unaltered overburden, the development of opencast activity[27,28,29,30] is evidently the simplest and the most immediate method of exploitation. The option for underground exploitation, imposed in the past by the technical-economic difficulties of removing thick overburdens, is nowadays a choice that may be introduced and sustained by different operational situations[31]. Environmental impacts and social acceptance of the activity may be another important reason for going underground[32 33].

The primary purpose of a dimension stone exploitation – unlike other quarrying activities – is to produce commercial blocks, that is, portions of sound rock with parallelepiped shape, with a volume generally varying between 2 and 15 m³, proper for further processing (mainly finalized to slabs or other architectural elements). However, it should be stressed that some dimension stones (e.g., some quartzite, slates, porphyries, etc.), cannot be extracted in form of blocks, but directly as slab-shaped elements.

Extraction methods[34] and the resulting marble block sizes[35] depend on the quarry in question[36]. The cutting process can be done either vertically or horizontally, depending on the shape of the area. The extracted blocks are classified according to their size, color and cleanliness.
The objective of a cutting technique is to create split surfaces, facing a reasonable cost and, in any case, without damaging the rock[37]. After the removal of overburden rocks covering the deposit, the production cycle of a stone quarry may generally be outlined in four operational phases: primary cut, overturning of the bench[38,39], squaring in blocks, material handling, block processing in site. The last phase is not always carried out in the quarry site.

In some quarries, according to the deposit characteristics (e.g. stratified deposits), the first three phases could be reduced to just one, when the blocks are directly extracted in their final dimension.
The selection of the exploitation method and the equipment among available technologies should be based on the different geo-morphological configurations of the deposit and the lithological characteristics of the material[40,41].

Technological progress[42] for dimension stone quarrying has made available a lot of options for performing the different operational phases in a safe and productive way, allowing for various choices according to the typology and the size of quarries, the mineralogical, petrographic and structural characteristics of the rock and, last but not the least, the assets of the enterprises. Figure 2 presents the principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case.

To loosen the block from the rock face, one can use various methods of making primary cuts. Continuous channels are made by sawing (most common), line (slot) drilling, jet burner or water jet (less common). Otherwise, cuts can be made by dynamic splitting (blasting), where explosives are detonated in a row of parallel drill holes. In some quarries, especially marble, all cuts can be made by sawing, whilst a combination of methods are used in others.

In most granite quarries, at least one cut (preferably the horizontal) is made with the use of explosives. Where present, natural fractures either vertical or horizontal, can be used as natural limitations for the primary block. In rare cases, wedging is used for primary cuts, especially when the primary blocks are small sized (e.g. sheeted granites).

After the extraction, the primary block is divided into slices (Figure 2.3), which in turn are tipped and subdivided to commercial blocks. In granite and marble quarries, such blocks are essentially larger than 3 cubic meters and have a rectangular shape. In slate quarries, such blocks are rarely thicker than 50 centimeters. The squaring is done by sawing, blasting or wedging, depending on the properties of the rock and the formation[43].

I sec. B.C. - middle of XVII sec.	Manual excavation by "cesurae". Use of simple tools: clubs, chipping chisels, drills, etc… Transport through sloping planes and wagons hauled by animals.
XVIII sec. until middle of 1900	Introduction of exploding substances. Blasting of huge portions of material through massive employment of explosive (black powder).
Second half of 1700	Introduction of first steam machines. Use of steam pumps for water pumping and first sawing plants moved by hydraulic wheels.
1854	Introduction of the "sand wire" in Belgium.
1855	Development of the first pneumatic drill (Sommelier).
1861	First operative pneumatic drill (railway tunnel of Frejus).
1876 - 1890	Construction of the marble railroad of Carrara.
1897	Development of the "penetration pulley" Monticolo for the execution of blind cuts by helicoidal wire.
1960 - 1970	Introduction of trucks for transport operations.
1964	Abandonment of the marble railroad of Carrara
1965	First experiences through chain saws in Belgium, on marbles.
End of the '60s	Progressive advent of the hydraulic drilling.
'70s	Use of water-jet in the exploitation of coal and soft rocks in Germany.
1970 - 1980	Introduction and success of diamond wire cutting technology with electroplated beads and chain saw with widia tools in marble quarries (Carrara).
1978	Use of hydraulic rock breakers and expansive mortars in Japan.
1978 – 1980	First applications of the high pressure water-jet on granite.
'80s	Massive introduction of wheeled loaders.
1980	Introduction of first diamond wires with sintered beads.
1986	Introduction of diamond wire cutters in granite quarries.
Middle of the '90s	Introduction of the diamond belt cutter.
'90s	Consolidation of the employment of hydraulic drilling and use of the hydraulic excavators in stone quarries.
Beginnings of 2000	Spread of diamond wire cutters, with sintered beads, in granite quarries.

Figure 2.2. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

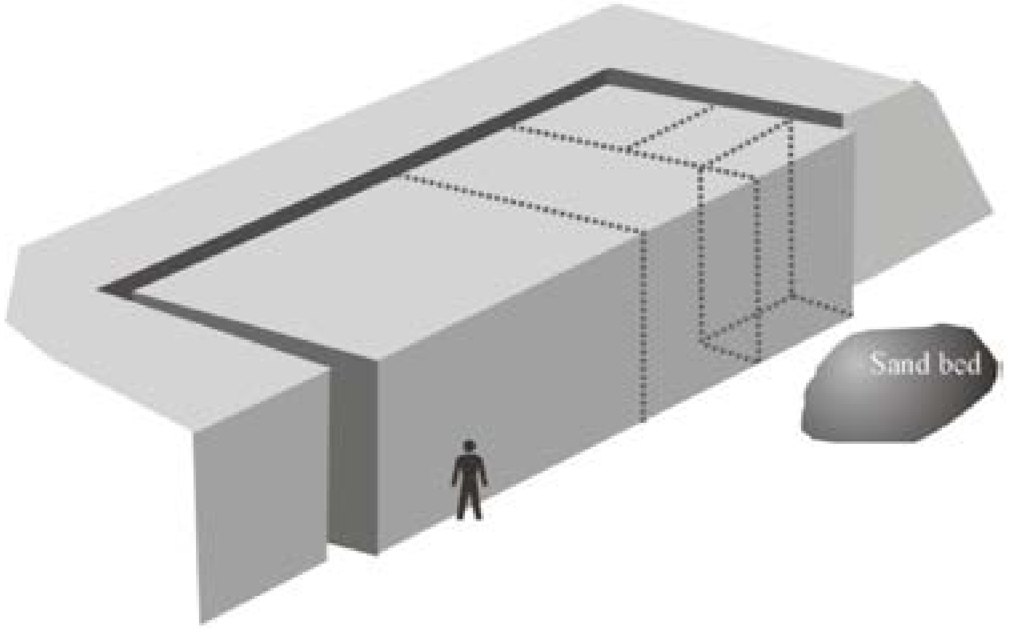


Figure 2.3. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

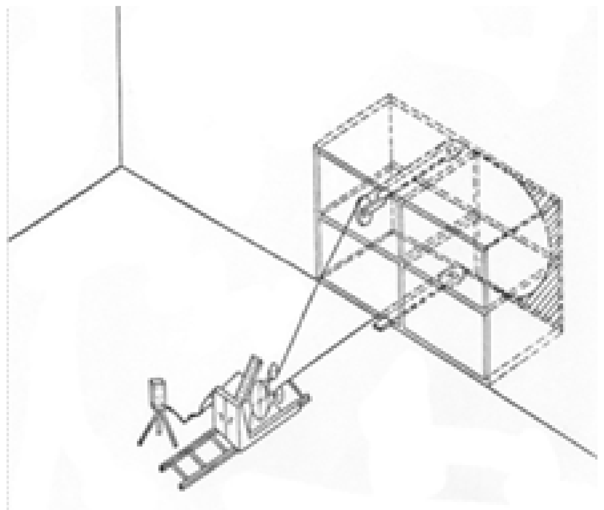


Figure 2.4. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

The key issue of all stone quarrying is to extract whole pieces of rock with as little damage as possible, and it is important to minimize the use of explosives. Furthermore, extensive knowledge of rock properties, such as grain orientations, natural cleavage directions, local stress conditions etc. is of vital importance for any quarrying operation. Even though the overall principle of extraction (from primary block to commercial block) is quite similar in most quarries, there can be large differences from place to place, depending on the rocks, local traditions and size of operation[44].

2.2 Machinery and equipment used in exploitation – Advantages and disadvantages

In the following text, some of the most important extraction techniques are described (Heldal and Arvanitides, 2004).

2.2.1. Cutting technologies

Drilling

Drilling in ornamental and dimensional stone quarries is predominantly used as an independent method, in combination with splitting techniques, or for continuous channeling (line drilling). It is also used as an auxiliary method for making holes for diamond wire cutting. Drilling equipment is either pneumatic (compressed air) or hydraulic.

The latter is gaining increasing interest, since it is faster, more powerful and consumes less energy. There are numerous varieties of specialized drilling equipment designed for any kind of quarry operation, from the extraction of primary blocks to the squaring of commercial blocks. In ornamental and dimensional stone quarries, accurate drilling is of fundamental importance, since even small deviations cause lower recovery and consume time and labor.

Sawing techniques

The use of saws for the extraction of stone blocks was applied as early as during the Roman Empire, and the use of wire saws gained significant importance in the industrialization of marble quarrying in the late 19th century. In recent years, sawing techniques have been improved significantly, and at the present time, sawing is applied in the majority of European ornamental and dimensional stone quarries.

There are many different saws for different purposes[45]. Wire sawing is the most widespread technique. Traditionally (and in a minor amount of modern quarries), a simple steel wire was used, and the cutting was facilitated by adding abrasives to the cooling water (helicoid wire sawing). In modern use, diamond coated beads on the wire do the cutting. The principle is simple – a wire is thread through meeting drill-holes, forming a loop around the rock mass, and by gradually moving the sawing machine on a rail backwards from the rock face, large vertical, inclined or horizontal cuts can be made. Such diamond wire saws have improved significantly in recent years, and from being a method most applied to marble and other soft stones, even granite can now be cut with great success.

Diamond wire sawing is best suited for massive (non-fractured) rocks. In quarries where the rocks are highly fractured, wire sawing can be difficult and slow, and in rare cases actually generate a lower block yield than other extraction methods. In some areas (especially in mountainous regions) the remnant (“stored”) stress in the rocks can be high, causing movements in the rock mass when cutting. The wire can easily get trapped in such situations.

Furthermore, wire sawing is dependent on running water, so that in areas were the winter is long and cold, the method may not be very practical. In Finland, the cold climate and high remnant stress are important reasons for that wire sawing is only used to a little extent.

Chain saws have become important in soft stone quarrying in recent years[46,47]. It looks like a larger version of a power saw for trees, with a mobile arm (“sword”) carrying a toothed chain – containing abrasives of tungsten carbide or diamond beads. It can work both with cooling water and dry. Cutting depth can reach as high as 6 meters. Chain saws are especially suitable for making “blind cuts”, e.g. for opening underground quarries. Chain saws are yet not applicable for quarrying of granite and other hard rocks. It is considered to work best in rocks with few fractures and homogenous structure. In open cast quarrying, it is especially suited for quarries with a regular layout and lowstep architecture. A modified chain saw is the diamond belt saw, carrying a belt around the “sword” rather than a chain. It works in similar way as the chain saw, but uses no grease or lubricants (more friendly to the environment). It is considered to be highly efficient in underground quarry operations, but cannot be used for hard rocks.

Disc saws are not frequently used for primary rock extraction, but some examples do exist. Disc saws can run on rails, or be mounted on an excavator[48]. Their size and performance vary considerably. They are used predominantly for vertical cuts, but there are also smaller types cutting two directions (vertical and horizontal) simultaneously.

Line drilling for continuous channeling (primary cuts) is generally considered to be an expensive method, and is essentially applied where other cutting techniques work badly.

Blasting

Although blasting in stone quarrying has been declined due to the improvement of sawing technology, there are areas and rock types were this is still considered to be the most efficient method of extraction. Especially, this is the case when either climatic conditions or rock quality makes sawing difficult or too expensive. In addition, drilling and splitting is frequently used in combination with sawing – both for one or more primary cuts and squaring.
The use of explosives in the extraction of ornamental and dimensional stone is a difficult art, and there are many different practices, depending on rock type, local traditions and experiences. Furthermore, rocks are not isotropic materials, so that their ability to split along a drill hole line can have strong, directional variations.

"Fast" explosives, such as dynamite, will generally crush the rocks so that they are not usable as dimension-stone. In traditional quarrying, especially for granite, "slow" explosive (black powder) in small quantities worked well, combined with a detailed knowledge of the natural splitting directions ("rift" and "grain") in the rocks. A spoonful of black powder in each of three central placed drill-holes can be sufficient to split a ten meters long and two meters tall quarry face. Black powder is still used in some modern quarries, essentially in granite production, but most common are detonating fuse (12 g/m, 20 g/m or 40 g/m) and tube charges with "reduced strength".
However, the traditional explosives (black powder, gel ammonite) are cheaper, and for that reason still in use in some small-scaled quarries or in quarries where the extraction costs must be kept to a minimum.

Wedging/splitting techniques

Wedging as a method of splitting[49] rocks was introduced in the Antiquity. Wedges, or "plugs and feathers", are placed in drill holes or pits in the stone to split, at regular intervals. By hitting the wedges, stress is created in the rock, and finally it will burst. Hard and brittle rocks, such as granite, are easier to split than softer ones. Furthermore, splitting properties show directional variations – where planar features, such as foliations and layering, are the easiest directions.

Wedging in modern quarries is predominantly restricted to the squaring of blocks – e.g. the subdivision of primary blocks extracted by blasting or sawing. Tools and methods vary considerably depending on rock type, local traditions and skills.

Other techniques

In addition to the above mentioned, there are other techniques that, with more or less success, are used in dimension-stone quarrying. Jet burner is a high temperature jet flame used for making channels in granite. The high temperature makes quartz-grains expand, with pulverization of the rock as a result. It only works properly for quartz-rich rocks. The use of this method is declining, especially since it is extremely noisy, dusty and because it is difficult to do other work in the quarry during channeling. More and more, wire sawing is taking over for making cuts in granite quarries.
High pressure (up to 350 MPa) water jet has not found any widespread application in the stone sector, but it can be expected interesting developments in the years to come. At present, the method is costly and slow, and it works predominantly on granites. One of the most interesting future potentials is probably for underground granite quarrying – in combination with diamond wire sawing.

Comparison of different cutting technologies

A comparison among different cutting technologies can be made on the basis of some objective parameters that surely influence the cost and the applicability[50]:
a) volume of rock to be destroyed per unitary surface of cutting (m^3/m^2); b) average productivity: cut surface per energy consumed in an hour (m^2/kWh); c) usual range of power of a single machine (kW); d) limits of height (or depth) h and of length l of the obtainable cut (m).

From the point of view of a pure unitary cutting cost, referred to 1 m^2 of surface, dynamic splitting is nowadays cheaper than mechanical cutting. It must not be neglected though that the unitary cost for splitting have to be correctly appraised with reference to the volume of useful blocks produced.

In comparison to other mechanic cutting methods, dynamic splitting causes a greater percentage of waste, whose economic effect depends on the intrinsic value of the material produced. The material value de-

pends on the type of stone but also on the phase of the productive process to which reference is made: since the commercial value of the stone grows with the processing progress, a less "precise" method, in case of highly appreciated material, could be advantageous only in the first stages.

Undoubtedly, the simplicity and the relative inexpensiveness of a method are important factors for its adoption. Nevertheless, other aspects have to be considered as well.
Firstly the safety and following the operative flexibility and the adaptability to the characteristics of the rock, along with the minimization of the environmental impacts. Furthermore, the most crucial element in evaluating a technology is its ability to maximize the block yield.

Currently, diamond wire is employed in many "hard" stone quarries. Plasticized or rubberized wires with sintered beads (34-40 per meter) are always used, whose performances, both in terms of productivity (m^2/h) and service life (m^2/m) have been notably improved in the last years.

A comparison of alternative cutting technologies is given for the case of the case of the "Dionyssos" marble quarry located at the Penteli Mountain, Greece. Real–scale tests have been conducted in order to examine the performance of a chain saw machine, originally designated for underground quarrying, in the open pit quarry exploitation[51,52].

2.2.2. Handling technologies

With "handling" are referred all the operations of loading[53], unloading, lifting, moving[54], etc. that concern either the extracted material (marketable or waste) or the operative machines. The equipment universally used for these operations are loaders and hydraulic excavators.

2.3. Geotechnical measurements & controls during the excavation

Large surface and underground excavations are commonly required for the extraction of natural stones. Due to their shape and size, such excavations significantly disturb the surrounding rocks and lead to significant stress redistribution around the excavation. The extent of disturbances and the rock mass response to those depends on the shape and size of

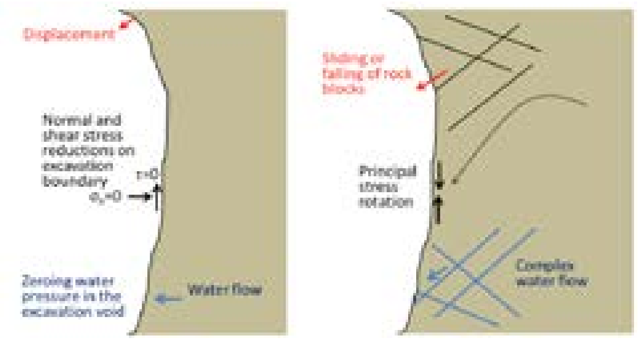


Figure 2.5. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

the excavation and the methods used, and on the mechanical and structural characteristics of the rock mass.

Since the in situ stress state is directly related to the local hydraulic conditions, their analysis is also essential for a stable design of the quarry excavations. For this purpose, a number of piezometers and phreatimeters are installed in the area of interest (Ferrero & Iabichino 2003).

Production of natural stones is essentially engaged in quarrying in hard rocks and therefore the stability of excavations is largely related to the presence of rock discontinuities, which can cause structural failures, as well as the conditions of stress and deformation of the intact rock and the rock mass. In order to ensure the stability of these excavations, application of the principles of rock mechanics57 and geotechnical engineering is required, from empirical methods to modern computational tools with explicit numerical simulation of the presence of rock discontinuities.

In addition, during the operation of the quarry, systematical geotechnical measurements are necessary to assess the response of the rock mass. Installation of modern instruments contributes to the control, monitoring and improving of the stability and safety conditions during exploitation of natural stones.

2.3.1. Geotechnical Assessment

A geotechnical assessment, preceded by a detailed geotechnical site investigation, is necessary to identify and assess all the factors that may affect the stability and the safety of a new or existing excavation. Information to be established during geotechnical site investigations at the initial stages of a quarrying project includes:

-Topographical and Geological survey and geological mapping
-Hydrogeological conditions
-Rock mass structure, indicating orientation and spacing of rock discontinuities
-Measurement of the stress conditions
-Geophysical surveys,
-Coring and laboratory tests.

Measurements of the natural stress field (i.e. in situ stresses before excavation) at the future quarry site are of paramount importance for the safe design of the underground excavations. The most suitable measuring method for natural stone quarries depends on the accessibility of the quarry site. A very concise presentation of the stress measurement methods is given in Ferrero & Iabichino (2003), while each method is described in detail in the relevant suggested method of the International Society of Rock Mechanics and Engineering (ISRM)

Method	Test
Relaxation measurements (stress release)	Wall relaxation Under-coring In-hole relaxation (overcoring, borehole slotting, etc.) Relaxation of great rock volumes (bored raise)
Pressure cells (stress restoration)	Flat pressure cell Curved pressure cell
Hydraulic	Hydraulic fracture

Figure 2.6. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

2.3.2 Stability of excavations

As already mentioned, quarrying of natural stones is a related to large excavations in hard rock. Therefore, the instability mechanisms that may occur depend on the geometrical and mechanical properties of rock discontinuities and on the strength of intact rock. A major concern is the stability of individual rock blocks that are delineated from the rock discontinuities and the free surface of the excavation (Figure 2.7).

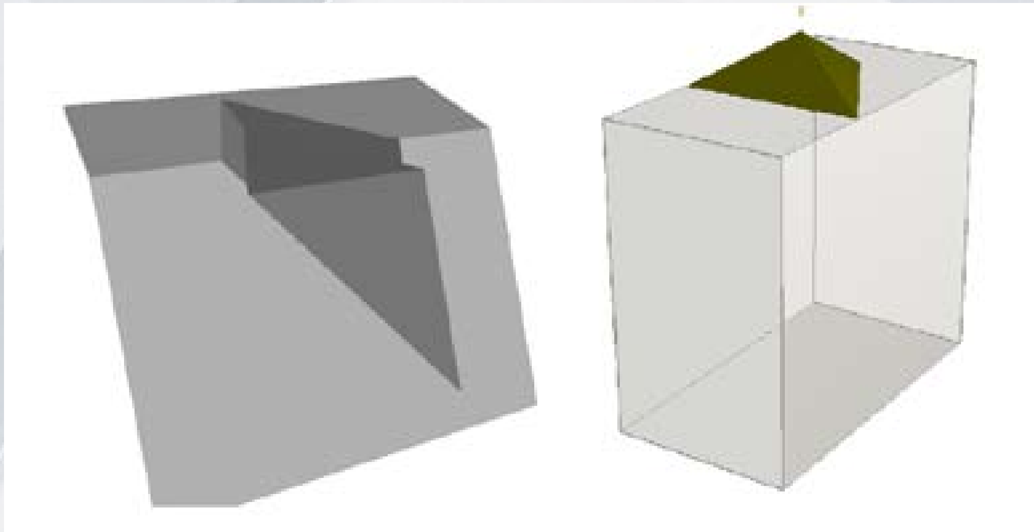


Figure 2.7. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

The stability of such potentially unstable individual rock block is commonly examined with limit equilibrium methods, for the calculation of their factor of safety and of the necessary support, which mainly consist of installation if a number of rockbolts of adequate capacity. Analytical design of rock support in such cases should be performed[62,63].

Another important instability mechanism is the potential failure of rock layers in the roof of an underground opening. Such failure may be prevented by careful design of the opening span and of the support system either to carry the whole weight of the failed layers or to assist the rock mass to carry its load.

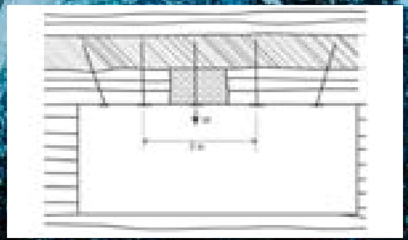


Figure 2.8. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

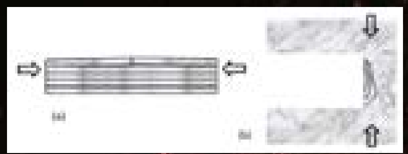


Figure 2.9. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

Depending on the geotechnical conditions of the excavation several geological factors may affect its stability[64]. In a surface quarry in a high stress buckling of surface rock layers may occur, while in an underground quarry high stresses may lead to spalling or even rockburst[65] of the excavation walls.

Further, when ground water is anticipated, grouting of the major discontinuities that act as flow channels may reduce the potential water ingress, although a continuous water pumping may not be avoided (Hudson 2014).

Although stone pillars in underground natural stone quarries are generally strong, due to the stone strength and the cross sectional dimensions of the pillars, the necessity of creating rooms with large height to facilitated excavation with benching may lead to several pillar instability mechanisms involving both failures of intact rock and/or along the pre-existing discontinuity planes[66,67].

2.3.3. Geotechnical monitoring

Monitoring of the mechanical behavior and response of the rock mass during the excavation and operation of the quarry requires systematic geotechnical measurements. The aim of the measurements is to ensure the safety of workers and equipment through control of the rock mass response around the excavation, to verify the assumptions made during the design phase and to provide information for the stress and strain changes during excavation and operation of the quarry[68].

Usually measured parameters during geotechnical monitoring are the rock mass displacements and stresses and the loads exerted on the supports. The systematic control and mapping of the displacements of the surface and underground walls of the excavations is carried out both topographically and with the installation of devices for capturing the rotation, displacement and convergence of the rock on the periphery of the excavation. These measurements are combined with further measurements of the deformation and stress of the rock mass in areas of interest (such as the roof or the pillars of an underground quarry) and are more necessary in areas with uncertainty as to the geotechnical characteristics of the rock mass and in more intensively fractured areas[69].

Modern topographical measurements (e.g. Total Stations, ground-based radar interferometry, GPS positioning and UAV Photogrammetry) facilitate a quick and efficient monitoring of the rock displacements. Other common devices employed for displacement measurements in stone quarries include crackmeters[70] and borehole extensometers[71]. Crackmeters are installed on opposite sides of a rock discontinuity to measure relative movement of its walls. Borehole extensometers measure the position of rod relative to a reference point, usually anchored within stable rock mass/anchor and thus they monitor the possible rock movement (rock mass strain) towards the excavation. Both measuring systems warn for any displacement that may precede an imminent rock mass of rock block failure.
Monitoring of stress changes in the vicinity of an excavation or within the pillars of an underground quarry provide essential information's about the effect of the excavation on the nearfield stress states. Two kinds of measuring techniques may be distinguished:

1. Absolute measurement of the stress field: this is facilitated mainly by the borehole overcoring methods. As pointed out by Ferrero & Iabichino (2003), these methods have a high cost and therefore they are not commonly employed in quarrying operations. However, some of them provide for the full stress tensor at the point of measurement. The CSIRO-type[72,73], stress measuring cell is installed in an over cored portion of the rock within a borehole. During overcoring that portion of rock is relieved from the surrounding stress and the CSIRO-type cell measures the components of deformation that are subsequently used to evaluate the 3D stress tensor.

2. Measurement of the nearfield stress changes within a borehole or in a rock cut. For example, the flatjack[74] test may be used to measure the stress variation during excavation advance in a surface outcrop or in the walls of an underground excavation.

A concise description of the devices that may be used for stress measurement may be found in Ferrero & Iabichino (2003).
The loads exerted on the support elements can also be measured during excavation. A very common measurement is the load carried by the rock

bolts used to stabilize the walls and roof of the excavation. This is implemented by anchor load cells[75] that are installed in critical locations of the quarry[76].

Newest developments of geotechnical measurements and control in natural stone quarries allow for a better understanding of the geomechanical response of the rock mass around the excavations. Recently, an innovative monitoring system by utilizing fiber optical sensors has been developed by Lanciano and Salvini (2020)[77], that indicates the potential of fiber optical sensors to be used for open pits and underground quarries monitoring. Further, acoustic emission techniques are now at a mature stage of development and they may be extremely efficient in early warning of an imminent collapse during excavation and operation of a natural stone quarry[78].

2.4 Environmental aspects during design and operation of natural stone quarries

Marble quarries are likely to have lesser impacts on natural and man-made environments compared to metal and coal mines or even aggregate quarries. Yet, they do present a typical range of adverse effects. Mineral workings cause the removal of top soil, damage natural fauna and flora, pollute ground water and soil and lead to soil erosion. Drilling and cutting operations for the extraction of marble blocks, as well as the movement of trucks over quarry and public roads, generate noise and dust nuisance[79,80].

Moreover marble quarrying is an energy intensive activity that requires relevant amounts of electric and thermal energy sources[81]. An important feature of the marble mining is represented by the high level of waste materials released during the quarrying process.
Both these elements call for careful attention to the production of this material, aiming for a suitable reduction of the environmental impact exerted by the current working procedures (Liguori et. al. 2008)[82].

Another significant problem is the production of large amounts of slurry that can be potentially diffused into the environment by runoff water and can impact local karst aquifers, negatively affecting the groundwater quality and generating a remarkable environmental and economic damage[8384.]

Excavations, stockpiles and waste heaps result in serious landscape degradation, forming geometrical features (i.e. benches, heaps, etc.) that replace natural topographic relief (Menegaki and Kaliampakos 2006). The latter causes a significant landscape disturbance, which is one of the most important environmental impacts given its irreversible character[85]. This fact could be the reason of public opposition against marble quarrying activity, especially in the case it located near urban areas. Hence, even though marble is probably the most popular ornamental stone in the world, marble quarries are usually faced with NIMBY ('not-in-my-backyard') challenges[86].

The European Union, in its attempt to set high and uniform efficiency and sustainability standards in the stone industry, has established the Eco-label brand as a tool for stimulating ecological behavior among producers and consumers. The EU Ecolabel criteria for hard covering products aim, in particular, at promoting products that have a lower environmental impact along their life cycle, are produced using material efficient and energy efficient processes, with reduced emissions to air, and reduced water consumption. Requirements for obtaining the Eco-label in natural stone industry are described in European Commission Decision 2021/476 of 16 March 2021 (ECD, 2021)[87]. The Eco-label awarding criteria are largely concentrated on the intermediate blocks of dimension stone from natural stone quarries. These are scored according to a matrix of five main indicators (namely: Energy consumption at the quarry; Material efficiency at the quarry; Energy consumption at the transformation plant; Water and wastewater management at the transformation plant; Reuse of process waste from the transformation plant) and four optional indicators (namely: Environmental Management System of the quarry; Environmental Management System of the transformation plant; Quarry landscape impact ratios; Regionally integrated production at the transformation plant). The total score is based on the sum of individual scores given for each indicator, multiplied by a corrective weighting factor. Quarries must obtain a weighted score of at least 30 points to be eligible for the Eco-label award.
The sustainability of the extraction of natural stones for building purposes, such as tiles and slabs, requires optimizing all phases of the production process from exploitation to final use[88,89].

For example the association of the use of photovoltaics and wind energy with a production facility could reduce significantly the environmental footprint[90].

In any case the natural stone sector is characterized by strong initiative for innovation in the whole production chain of the natural stone sector from exploration, to post closure and final uses[91].

2.4.1 Waste management

One of the main environmental impacts of the natural stone extraction process is the production of huge volume of wastes that in some cases equals to 95% of the extracted rock, like in the case of the calcitic marbles located at the region of Eastern Macedonia and Thrace (N. Greece)[92].
The natural stone waste, although composed of the same material substances as the solid rock from which it has derived, is not in the same physical condition because it was disaggregated, mixed and moved to a different place.

The essential difference between the types of waste produced in natural stone quarries is the size. The wastes could present very large particle size distribution, from blocks without the necessary characteristics for processing, or small blocks which are the result of grinding and finishing processes, to particles of smaller sizes, with can reach a few microns, in the form of mud resulting of cutting and polishing in the finishing operations.
The greatest part of the waste has mineralogical composition and chemical properties identical to those of the useful rock; consequently, the distinction between "saleable product" and "waste" presents a notable degree of elasticity, according to the different uses and possible reuses.
From a wider perspective, appropriate for the politics of sustainable development, it seems that it is more convenient to refer to management of waste in terms of "treatment" rather than "disposal", in order to favor for a recovery as extensive as possible. Moreover, the utilization of the marble wastes will substantially contribute to the recovery of significant economic value for the quarry.

2.4.2 Quarry rehabilitation techniques – Implementation of alternative land uses

The most intense environmental problem that a marble quarry confronts does not occur during the operation but after the closure of the quarry, at the post-mining stage. The problem is related to the rehabilitation of the quarry site and it has resulted in serious conflicts between local authorities, the public and the mining companies. In a typical case the quarry would be abandoned without any attempt to restore the site or is rejected and mining activity in general is perceived as hostile to the interests of the area[93].

To this end rehabilitation of abandoned stone quarries could play an important role as a component of building a smart city[94].

The roots of the problem lie in two key factors: mining companies' former behavior and legislation. In the past the mining companies have consistently considered the rehabilitation of the quarries as an issue of minor importance. Therefore, the attempts to restore the quarry sites were not carefully planned and many important parameters such as the socio-economic, cultural and historical aspects of the particular area were often neglected. Moreover, legislation has strongly supported the restoration of the abandoned marble quarries by means of backfilling and re-vegetation, a practice that has proved to be ineffective and in some cases has further aggravated the problem. Re-vegetation cannot be effectively applied in marble quarries because of: The smooth and flat surfaces of the benches, that wire-saw cutting produces are subjected to soil erosion. The hard surface of the marble hinders the development of an adequate root system and the plants eventually shrivel.

The climatic conditions deteriorate the above conditions.

It is becoming apparent by all parties involved that the term restoration does not reflect reality, nor should it be linked with re-vegetation. After the mining activity many parameters, like the original contour of the landscape, have completely changed and it is impossible to restore the original conditions. Accordingly, when the surrounding area is predominately arid and vegetation is scarce, the planting of trees is bound to fail. The alternative approach that has been gaining supporters is rehabilitation. By definition rehabilitation modifies the site with a view to establishing new land-uses. When rehabilitation is applied, it takes into consideration the needs of the local community, urban planning and the characteristics of the area. Furthermore, the final plan allows for a diversity of needs to be fulfilled and can be both feasible and acceptable by all parties. Moreover, stone quarries often create peculiar geometric spaces that may offer stimulating project alternatives for rehabilitation and reuse, in comparison to the simple return to a "natural" landscape. As a reference, the case of the Lithica Quarry of s'Hostal, Menorca, Spain is reported, in which the rehabilitation of stone quarries led to the creation of particularly significant place. In 2019 the site has been awarded by the European Heritage Awards/Europa Nostra[95].

The selection among rehabilitation alternatives should be based on specific criteria. In case where there are few quantitative parameters available, the Fuzzy AHP can be proved useful as it takes into account both qualitative and quantitative characteristics, via the pairwise comparisons[96].

The good thing is that nowadays a lot of stone quarries transformation projects have already been realized[97,98].

Health and safety in quarrying operations

Natural stone quarrying is a high importance economic sector both in Europe and worldwide. The production of raw stone materials gives rise to many other economic sectors within an industrial economy and contributes to a significant degree in the economic prospect of a country or of a region. However, there are many uncontrollable factors both during exploitation and during handling of materials that may lead in severe accidents thus making the natural stone mining and quarrying sector one of the most dangerous branches of industry from a health and safety perspective. Therefore, prevention of occupational accidents is of outmost importance for the sector. This is facilitated by knowledge of the specific risks related to each quarrying operations, planning the appropriate prevention measures and apply the relative regulations as implemented in each case.

3.1 Risks related to specific operations and working positions

Ersoy & Yesilkaya (2016)[99] divide the possible accident fields in marble quarries into seven categories, depending on the position and the operation of each field.

On the quarry roads, the products, waste, labor and machinery are transported by trucks or buses, creating conditions of increased traffic that often lead to accidents. In addition, possible errors in the loading of machinery, equipment and mining parts, as well as their insufficient fastening during transport can be the cause of accidents.
Many accidents are caused by limited space or mishandling of construction machinery during removal of the overburdens to access the exploitable natural stone deposit. In addition, before the block cutting process, the use of compressed air to clean the area exposes the workers to increased noise, dust and possible ejection of small pieces of rock.

The drilling required during the production process exposes staff to risks related to noise, vibration, dust and mud, creating an unfavorable environment for occupational diseases and accidents. During the cutting of the marble with wire cutting, it is possible that the workers are seriously injured during the initial movement of the wire. But even more important is the risk of serious injuries if the wire cable is broken, either due to age or excessive stretching. The same hazards exist also when sizing and dimensioning the stone blocks. Accident hazards are also created during low cutting with a chainsaw, as the accumulated mud must be transported.

When detaching the stone blocks from their natural position, serious and fatal accidents can occur if the block slips or if the workers slip and fall between the block and the main rock.
Another possible hazard is related to fire and explosion due to leakage or inadequate handling of fuels used for the production machines. This is also relevant to the electrical motors, where electrical leakages may expose the workers in risk of electric shock.

Very high quarry boundaries that are formed in open pit quarries impose geotechnical risks of rock block falling or even bench or total quarry slope failure. Also, they constitute dangerous areas for the workers due to the abrupt inclinations. Working on quarry benches also is an area of risks, both due to the limited bench space (to facilitate quick production) and due to the risk of slipping and falling from the bench. Several risks also exist when working in the front face of the bench, related both to the rock block fall and to the materials fall. Several risks are also imposed during working waste disposal, in the fields of block stock, and in the storage areas.

Further, specific risks exist that are related to particular operations and working places of the quarrying activities. A list of specific risks is given by Bertoni et al. (2003), including risks related to front stability in surface quarrying, surface soil quarrying with deep cavity, underground quarrying, as well as health risks, associated with noise, vibration, dust and gas.

3.2 Preventive measures

With the help of risk assessment, an initial approach to the problem of health and safety is provided, giving qualitative and quantitative risk indicators, the actions to be taken to eliminate or reduce the risk and the required timetable for the implementation of these actions. In each case of risk, appropriate safety measures should be designed with a view to minimizing accidents at work and health problems. The preventive measures to be taken follow the following principles[101]: Elimination of the risk through redesigning the activity or equipment, reduction of the risk at source through engineering controls, minimizing the risk through procedural controls, use of appropriate personal protective equipment (PPE).

An extensive list of preventing measures in quarrying has been developed on the SAFEQU-project[102] related to the health and safety in the workplace. The following preventing measures is a partial list extracted from the results of the abovementioned project.

3.3 Knowledge of the European regulations on Health and Safety

There are two European directives related to health and safety in the mining and quarrying sector.

Risk	Preventive measures
Falls from height	All differences in height are protected with rigid elements (fences, etc.). Risks of fall are signed. A distance of security of 5 meters is respected. Ladders are used to gain access to different heights Harness or safety belts are used if collective safety measures are insufficient.
Falls and slips	Working areas are kept free of mud. Walking or moving areas are kept free of mud. Safety shoes are used. Vehicles (all-terrain vehicles) are used to move if it is possible. All objects are out of displacement areas Power shovel´s driver keeps walking areas free of objects.
Falling objects caused by collapse or displacement	All parts that made up quarry facade are stable against landslide. In case it is not possible, hazard area is enclosed. Obstacles are not near places with different heights. All areas with risk of landslide are protected
Trapping in or between objects	Mobile parts of machines are covered by frameworks Handling loads can also cause trapping. When depositing loads on a surface (floor, table, etc) it is always done with care. Worker do not wear loose clothing, bracelets, chains...that can be trapped by machines in movement.
Trapping under machines or vehicle	Traffic rules are respected State of vehicles is regularly checked. Vehicles transit areas are enclosed. Caution is maximized in areas with slope, curves, etc. The presence of workers near to vehicles or heavy machinery is avoided.
Direct Electric Shock	Plugs are duly fastened, clean and without accessible active parts. Defects in insulation of wires are repaired immediately. Repairs on wires insulation are never done with insulation tape. Wires are completely replaced or tight boxes are used. Workers keep a safe distance from high-voltage facilities. If it is necessary, the area is enclosed using flashing lights.

Figure 3.1. Principal steps of technical evolution in the exploitation of dimension stones, with main regard to the Italian case (Cardu and Lovera, 2004)

Council Directive 92/104/EEC[104] of 3 December 1992 concerns the minimum requirements for improving the safety and health protection of workers in surface and underground mineral-extracting industries. For the purpose of this Directive, surface and underground mineral-extracting industries shall mean all industries practicing surface or underground extraction of minerals, and/or prospecting with a view to such extraction, and/or preparation of extracted materials for sale, excluding the activities of processing the materials extracted.

The Council Directive 92/91/EEC[105] of 3 November 1992 concerns the minimum requirements for improving the safety and health protection of workers in the mineral-extracting industries through drilling. This directive concerns all the industries practicing extraction of minerals through drilling by boreholes, prospection with a view to such extraction, and/or preparation of extracted materials for sale, excluding the activities of processing the materials extracted. A number of rules for the employer's obligations are set: general obligations, protection from fire, explosions and health-endangering atmospheres, escape and rescue facilities, communication, warning and alarm systems, keeping workers informed, health surveillance, consultation of workers and workers' participation, and minimum requirements for safety and health. Concerning the minimum requirements for health and safety, they are laid down in the Annex of that Directive.

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Manufacturing

History of stone sector and its own significant

Properties of natural stone as building material

Testing of mechanical properties in building materials

Different types of manufacturing the stone elements for specific designs

General references

Natural stones are one of the oldest building materials. The first uses of natural stones from the early humans were as tools and weapons. Nowadays, the natural stone sector, like any other industrial sector, requires a technological contribution from standardisation to facilitate its promotion and development, where manufacturing of the stone also required specialized knowledge to be able of producing materials with the quality level required by the national and international markets.

On the other hand, the industry must count with local qualified and certified laboratories guarantying the customer that the delivered materials totally fulfil all the requirements of the order. These laboratories need highly qualified staff, which only HEI's can supply. So, additionally, another topic covered in this eBook is focused on this knowledge to provide future students with the required skills and competences.

History of stone sector and it's own significant

Rock or stone is a naturally occurring solid aggregate of minerals and/or mineraloids. Natural stones are one of the oldest building materials[1,2,3]. The first uses of natural stones from the early humans were as tools and weapons. In fact, the Stone Age, the first period in the three-age system frequently used in archaeology to divide the timeline of human technological prehistory into functional periods, was a broad prehistoric period during which stone such as flint or obsidian was widely used to make tools with an edge, a point, or a percussion surface (Fig. 1)[4,5].

Figure 1: Stone tools of early humans

The oldest stone tools were excavated from the site of Lomekwi 3 in West Turkana, northwestern Kenya, and date to 3.3 million years old.

Throughout human history one can find several examples of great monuments made from natural stones, such as the Stonehenge in the U.K., the Pyramids in Egypt, the Parthenon in Greece, the Colosseum in Italy etc. Natural stones have been also used in works of art such as statues, decorative artefacts, fountains etc.

Figure 2: Stonehenge monument in the U.K.

Figure 3: The pyramids at Giza, Egypt

Figure 4: The parthenon-near Athens

Figure 5: The colossseum in Rome[6]

1.1 Essential requirements for natural stone products.

The natural stone sector, like any other industrial sector, requires a technological contribution from standardisation to facilitate its promotion and development.

The existence of standards in the natural stone sector seeks to achieve the following benefits[7]:

At the extraction level: rationalisation, modernisation and technification of natural stone mining operations.

At the transformation and processing level: improvement of natural stone treatment processes, through a broad knowledge of the products and their application possibilities.

At the marketing level: increasing and improving the quality of the supply of natural stone, product promotion and market regulation.

Among the most basic product specifications of natural stone are those related to its appearance.

The appearance of the material is defined from a set of characteristics that determine the appearance of the faces exposed to use and that have to do with both the nature of the rock and the finish or completion of the product, obtained in the manufacturing process.

Its declaration by the manufacturer is considered mandatory, as it forms part of the product identification in the declaration of performance and in the CE marking (UNE-EN 1341 Annex ZA, UNE-EN 1469 Annex ZA, UNE-EN 12057 Annex ZA and Annex ZB, and UNE-EN 12058 Annex ZA,)[8,9,10,11]. It consists of two parts: designation and surface finish. Optionally, it can also be accompanied by reference samples.

1.1.1 Designation of natural stone products.

Natural stone products are identified by the manufacturer by means of their "denomination", a term which, according to the UNE-EN 12440 standard, comprises 4 characteristics:

Trade name: a term chosen by the manufacturer for commercial purpo-

ses, which is sometimes also a traditional name in the market, used by different producers and which can often refer to a specific type of rock, a place of extraction or certain colour characteristics.

Petrographic name: scientific name of the rock obtained from a petrographic examination, in accordance with UNE-EN 12407 and UNE-EN 12670.

The petrographic name: examination may result in different names for the same rock, depending on the depth of the study and the classification systems adopted.

Place of origin: at least the municipality, region, and country of extraction. The name of the quarry is often mentioned.

Characteristic colour: general colour or range of majority colours of the stone, observable with a given surface finish.

The colour can be expressed descriptively from observation on dry, clean surfaces, in daylight in the shade. Sometimes the colour may be defined by an alphanumeric classification code established by the manufacturer. It can also be determined with a colourimeter or spectrophotometer and expressed using different notation systems or standardised scales (Munsell, CIE L*a*b*, Yxy, etc.).

1.2 Different types of natural stone and applications in new era in specific buildings

There are three basic types of rocks in nature: igneous, sedimentary and metamorphic. The first ones derive from the solidification of magma located below the earth surface. The second originate ones from the depositing of detritus of existing rocks and/or animal and vegetal remains. Finally, metamorphic rocks derive from a deep transformation of existing rocks, caused by physical and chemical agents (pressure and temperature)[12].
Among the variety of rocks on earth, the focus will be placed on those that can be cut into slabs and used for ornamental purposes. According to a commonly used product classification, these materials can be divided into four groups: marble, granite, stones and travertine[13,14].

Marble includes all basically carbonate rocks, with a more or less homogeneous crystalline structure, which can be polished.

Granite includes all intrusive and metamorphic magmatic rocks of silicate origin, which are solid and can be polished.

Travertine is a sedimentary calcareous rock of chemical origin, having a typical vacuolated structure; some varieties can be polished.

Stones include a wide variety of lithotypes and are generally not polished. Depending on their behaviour when processed, they can be divided into two groups, soft and/or poorly solid rocks and hard and/or solid rocks.

More details on the commercial definitions can be found in the European Standard EN 12440 Natural Stones – Denomination Criteria.

There are also natural stones obtained from nature and used in the jewelry industry. The most known and preferred quartz are turquoise, amethyst, agate, amber, and onyx.

Knowledge of the properties of materials is basic parameter i design phase and building of the structure, including the different structures. For students and other interesting peoples which are involved in design and building phase or in future are planed to be oriented in this field, this course is manual for applications, because the technology of development the materials is on grooving process.

The building structures include the different types , such are: roads, railways, bridges, tunnels, hydrotechnical structures, airports, industrial structures, residential structures, cultural heritage structures, sports structure, etc.

In first design phase, respectively in conceptual phase it important also to involve environmental impact and in second phase it important to involve place and development of the materials. The selection of the materials includes the different factors, such

are: price, material properties, durability of the materials, placement and effect of time in complete the structure.

In this first phase is more important to have in mind:

The selection of materials is not completed if we propose just the generalized materials such are: concrete, steel, wood, aluminum, and require to complete with specific for specific used and positions, or selections will include the simple calculations.

And the properly selections of materials for used is necessary to include all the parameters:

- Basic knowledge of the materials

- Knowledge of the specific properties of the materials

- Properly used the proposed materials in function of environmental conditions

But also in selection process of materials in different cases need to have the : architectural conditions: lightning, colored of materials, and specific architectural requirement.

Different materials are in relations with different design or specific requirement of buildings, such are: free span, acoustic effects. thermal effects, lightning effect, etc.

Figure 6: Stone such material in bridge structures

Figure 7: Stone such material in castle and wall[15]

Exploitation of natural stone such building material passed the different phases and always is in the relations of type of massive stone.

Like the cookies above, natural stone is formed in layers. These layers may be made up of different materials and may or may not be the same color. Since the top layer is exposed to the elements, its appearance changes accordingly. This phenomenon is known as "weathering." Above, the embossed decoration on the top of the cookie represents this weathered face (sometimes called the natural face).

Figure 8: Stone in different layers / like cake

Confusion sometimes occurs when the orientation of the cookie is not taken into account. Remember, cookies can be installed either horizontally or vertically. As a result, the various points of reference – height, depth, and length – will change accordingly.

1.3 Why natural Stone and applications?

Stones are among the very first materials to have been used by man to build houses, monuments and other kinds of buildings[16]. The earliest form of stone construction is known as dry stone, or dry stacking. These are freestanding structures such as field walls, bridges and buildings that use irregularly shaped stones carefully selected and placed so that they fit closely together without slipping. Structures are typically wider at the base and taper in as height increases. The weight of the stone pushes inwards to support the structure, and any settling or disturbance makes the structure lock together and become even stronger. Dry stone structures are highly durable and easily repaired. They do not require any special tools, only the skill of the craftsman in choosing and placing the stones.

Today, the most common applications of dimensional stones are facings and floorings, both internal and external, funerary and sacred art, structural applications, special works, such as refurbishing, restorations and roofings, staircases, interior (skirting boards, doorstones, window sills) and exterior (window ledges, doorstones, copings, profiles) decoration and furnishings[17]. Summarizing the main applications of stones, except those concerning the structural field are[18].

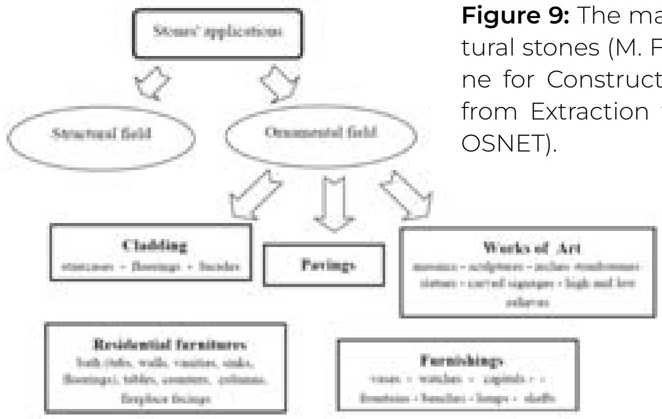
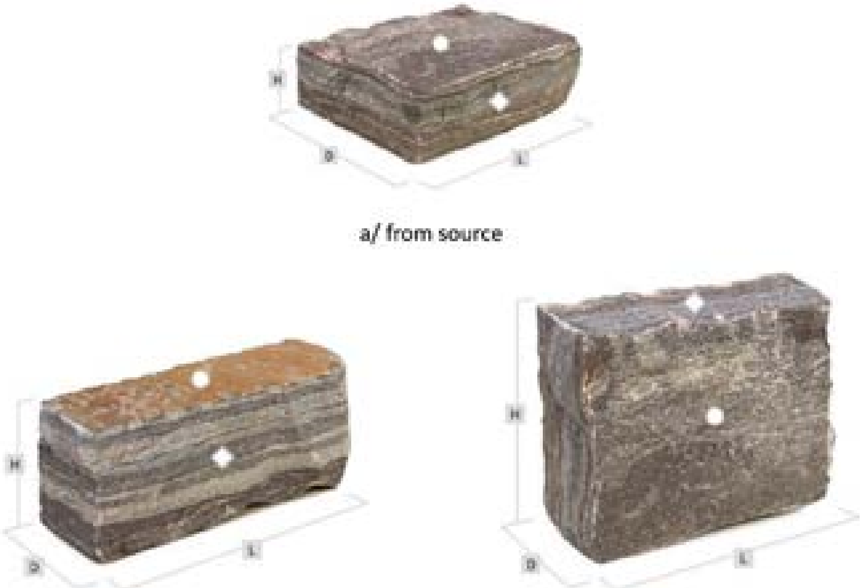


Figure 9: The main applications of natural stones (M. Founti (ed.), 2004. Stone for Construction and Architecture from Extraction to the Final Product, OSNET).

Each and every stone has its own texture and color, ensuring a truly distinctive look for your project. Each project is truly one of a kind! Using natural stone for your project or landscape elevates the site from utilitarian to a unique work of art.
A sound choice for both architecture and landscaping, natural stone withstands the passage of time, the elements, and provides a legacy for future generations. It unites structural integrity with diverse textures and an earthy palette to transcend popular fads. Quite simply, no other building material can match its beauty, strength and durability.

Formed over millions of years, our stone products are available in a wide variety of cuts and colors, each with an inherent beauty and durability only Mother Nature can provide.

1.4 Geometric characteristics and surface effect of stone



The natural surface of the stone without any mechanical modification applied. In this example, the split face of our Corinthian Granite is shown in Fig 13[19].

The face of the stone is pitched along a given line to achieve a bolder, more pronounced surface effect than a natural or sawn edge. This technique is also used to align adjacent pieces of stone along a particular plane, shown in Fig 14[20].

Figure 10: Split face of Corinthian Granite

Figure 11: Align adjacent pieces of stone along a particular plane.

Properties of natural stone as a bulding material

Natural stones (marbles, travertines, granites, etc.) have a wide range of applications in the construction sector as structural and coating materials. Marble, for example, finds a plethora of applications for decorative and structural uses, on exterior walls, on floors, for interior decoration, on stairs and corridors as well as for architectural purposes. It is also used in sculpture from ancient times until today, with many monumental sculptures made of marble. Other natural stone, such as travertine (a very popular type of limestone), limestone, sandstone and slate are often used in structural applications, in internal and external claddings, in paving, etc.

Figure 13: Marble fountain "Fox Marble Holdings PLC"

Natural stones have a wide variety in their physical and mechanical properties, largely determined by their geologic origin and petrographic characteristics, and on which their suitability for various applications depends. It is therefore necessary to thoroughly analyze both the required properties and the methods used to determine them.

2.1 Natural stone characterization and its practical importance for applications

The laboratory characterization of natural stones is based on the use of a wide range of tests[21], which may be divided into petrographic, chemical, physical and mechanical properties[22].

The different type of natural stones will be classified according the main properties and the analyzing from geological aspect the main representatives of the geological origin are presented in table 1. The geological ori-

Geological origin	Types of natural stones
Igneous	Granite, Granodiorites, Diorite, Basalt, Syenite, Gabbro
Sedimentary	Sandstone, Limestone, Travertine, Dolomite
Metamorphic	Marble, Slate, Quartzite, Gneis, Serpentine, Onyx

Table 1: Some of the most common natural stones by geological category.

Figure 14: Igneous rocks (2021, Kosovo).

Figure 15: Metamorphic rocks (2021, Kosovo).

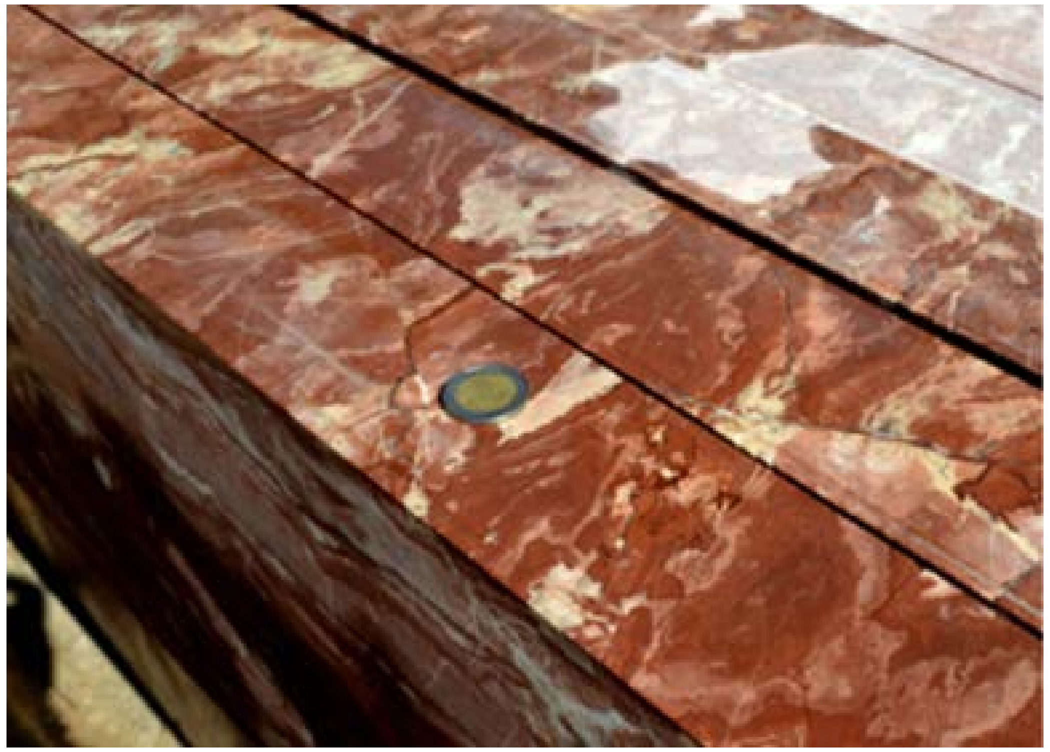


Figure 16: Sedimentary rocks in Albania

gin and the name of the rock can give the first crude information about its mechanical properties. Also, the age of the rocks is related to hardness, strength, porosity and other physical and mechanical properties.
Igneous rocks are composed of a crystalline set of minerals, such as quartz, plagioclase, pyroxene, mica, etc. Sedimentary rocks are composed of clastic particles and cobblestones of other rocks, in a matrix of clay minerals, clay, etc. By their nature, sedimentary rocks contain voids, some of which may form an interconnected pore system. Metamorphic rocks are formed by the effect of temperature and pressure or hot liquids on other rocks, sedimentary or igneous[23].

2.1.1 Mineralogical properties

Being aggregates of minerals the properties of rocks are dependent upon the character of these constituents, identified by their physical properties such as hardness, cleavage, streak, colour, lustra, specific gravity and shape og crystals. Some minerals feature great strength , hardness and resistance to chemical attack; others have poor strength and readily soak in water (gypsum); some minerals display a great tendency to cleavage and split readily along one or several directions (mica), thus decreasing the strength of the rock they make up. Some of important properties of minerals are as follows[24]:

Hardness- is probably the most important property for rapid determination of minerals. It is measures by scratching the mineral with a series of substances of known variation in hardness using the scale of Mohs.(example Talc with value 1 and Diamond with value 10)

Cleavage- is the measure of the capability of some minerals to split along certain planes parallel to the crystal faces. The various types of cleavage seen in the minerals are: Basal, Prismatic, cubic, rhombohedra and Octahedral.

Streak- is the color of mineral in powder –form. For some minerals , their color is seen to be entirely different from that of their powder, which makes streak a useful property in identifications of minerals. Streak can be readily observed by scratching it on a streak plate made of unglazed porcelain or roughened glass.

Color-is valuable characteristic of metallic minerals, but less reliable for non-metallic minerals.

Luster-is shine on surface of mineral and its appearance under reflects lights is classified as vitreous (glassy), greasy, pearly, resinous, etc,

Crystal- The crystal form is of importance when mineral had the opportunity to develop its natural shape.
The most common mineral constituents of building stone together with their chemical compositions and importance physical properties are presented in Table 2[25,26]:

Përmbajtja e SiO_2 në përqindje	Shkëmbinj të thellësisë	Shkëmbinj të sipërfaqes (kompakt)	Moneralet shkëmb-formuese	Masa vëllimore kg/m^3	Rezistenca në shtypje MPa
ACIDË SiO_2>65%	Granitet	Porfire kuarcore	Kuarc, shpate, fushore, mika	2600 2700	100 - 200
MESATARË SiO_2: 50-65%	Sienite Diorite	Pofire e trahite; Andezite e profite	Shpate fushore mika Shpate fushore	2600 2700 2500 3000	120 - 250 100 - 300
BAZIKË SiO_2<50%	Gabro	diabaze bazalte	Shpate fushore	2900 3300	200 - 500

Table 2: Mineral constituents together with chemical and physical properties

2.1.2 Physical properties of natural stone

Natural stones are heterogeneous and complex geomaterials. This heterogeneity becomes more pronounced with the presence of voids, such as pores and micro cracks, which are often partially or totally filled (saturated rock) with fluids. When studying physical properties, rock is considered to consist of solid components (minerals, binder), water (or other fluid) and air.

Porosity is defined as the percentage of stone volume occupied by voids. Porosity, as a fraction of the volume of voids over the total volume, takes values between 0 and 1. It can also be expressed as a percentage (%), between 0 and 100%.

The density of a stone is its mass per unit volume. It has physical dimensions of M·L-3 and is expressed in kg/m3 in the metric system. Specific gravity is the ratio of the mass of the natural stone to the mass of the same volume of water.

Water content or moisture of the rock is the ratio of the mass of water content in its voids to the mass of its solid components, expressed as a percentage. The moisture of the rock in situ is called natural moisture (natural water content). Natural moisture significantly controls the processes of mechanical disintegration of the rock, especially during the cooling-thawing cycles. In addition, it significantly affects the strength of the rock.

Degree of saturation is defined as the ratio of the volume of rock voids occupied by water to the volume of voids. A saturated rock has a degree of saturation equal to 100%.

In relation to the moisture and degree of saturation of the natural stone, three density types may be distinguished[27]: the dry density (the ratio of the mass of solid components to the total volume of the rock), the bulk density (the density of rock with natural moisture content), and the saturated density (density of saturated rock).

Absorption is the ability of a stone to absorb water when immersed. The absorption value is usually expressed as a percentage of the initial dry weight of the stone samples.

Abrasion resistance is generally defined as the capacity of the stone to resist rubbing actions from an abrasive material. Although it may also be considered as a strength property, it is largely depends on the mineralogical composition of the rock.

2.1.3 Mechanical properties of natural stones

The main mechanical properties of natural stones are the strength and deformational characteristics.

Compressive strength of the stone is the stress (i.e. the ratio of the applied force to the cross section of the specimen) that the stone can withstand in uniaxial compression. Flexural strength is the capacity of the stone to withstand bending loads, and it is usually referred to thin specimens. For thicker natural stones specimens the modulus of rupture (with units of stress) is commonly evaluated by transverse loading of a beam shaped specimen. The deformational characteristics of the natural stone are usually given by the modulus of elasticity (or Young's Modulus) which expresses the stress-strain relation of an elastic material and specifically the ratio between the changes of stress to the change of the strain. Natural stones are not really elastic materials, however, they may be considered to behave elastically at a certain range of their loading capacity, usually far enough from their maximum capacity.

2.1.4 Mineralogical effects on physico-mechanical properties

The shape, size and arrangement of the mineral crystals or grains of the rock affect its mechanical properties. Many igneous rocks have is crystalline tissue and their strength is the same in all directions. In contrast, in many metamorphic and sedimentary rocks, schistocity and stratification cause differences in strength with respect to the direction of loading. For the same petrographic category, fine-grained rocks generally have higher strengths compared to coarse-grained rocks.

It has been found that marble mineralogy and texture largely influences the thermoplastic properties and micro cracking degradation[28].

2.2 Laboratory tests for determination of physical properties of natural stones

2.2.1 Determination of dimensional tolerances in natural stone

These tests establish the maximum permissible dimensional tolerances or deviations for natural stone tiles.

2.2.1.1 Scope

This procedure is applied to natural stone (marble, limestone, granite, slate, sandstone, etc.) and agglomerated stone, whether treated with surface coating products, for use as dimensioned pieces in construction, countertops, furniture and other ornamental uses.

The European standard UNE-EN 16301 makes it possible to evaluate the stain resistance of natural stone products, which can be useful for selecting a stone according to its application in spaces exposed to splashes: kitchens, cafés, bathrooms, etc.

2.2.1.2 Reference documents

UNE-EN 1341:2013: "Slabs of natural stone for external paving. Requirements and test methods".
UNE-EN 1469:2015: "Natural stone products. Slabs for cladding. Requirements".
UNE-EN 12057:2015: "Natural stone products. Modular tiles. Requirements".
UNE-EN 12058:2015: "Natural stone products. Slabs for floors and stairs. Requirements".

2.2.1.3 Method

The nominal dimensions of natural stone tiles or slabs are identifying characteristics of the product and must therefore form part of the documentation accompanying the CE marking, or they may be included in the declaration of performance and the CE marking.

Natural stone tiles and slabs with regular shapes are defined by 3 nominal dimensions: length, width and thickness, commonly expressed in centimetres: However, standards UNE-EN 1341, UNE-EN 1469, UNE-EN 12057 and UNE-EN 12058 establish that the declaration is made in millimetres. Tiles with special or irregular shapes may require information by means of diagrams or drawings.

The rest of the dimensional characteristics (flatness or flatness of the faces, orthogonality of the angles, straightness of the edges, etc.) are generally not declared, although they should be checked in the factory.

The dimensional characteristics can be determined by means of the UNE-EN 13373 standard. However, the large number of measurements to be made on the product, in accordance with this standard, makes it convenient for the manufacturer to use any other quicker and simpler measurement procedure, provided that it offers an equivalent degree of precision.

The control of geometric characteristics may also require the use of statistical procedures for the design of the sampling, the most universal being the one based on inspection by attributes included in the UNE-ISO 2859-1 standard.

By means of such procedures it is possible to know the level of guarantee of compliance with the dimensional tolerances, and therefore to declare it or agree it with the client. Given the nature of these properties, a guaranteed level of 95% can be assumed in most cases.

The most common tile and slab formats have an exposed surface area of between 300 x 300 mm and 600 x 600 mm, and a thickness of between 10 and 30 mm. The reason is that larger formats also require greater thicknesses, which greatly increases their weight and makes handling and installation extremely difficult. It should be borne in mind that, in general, the recommended maximum weight not to be exceeded under ideal handling conditions is 25 kg.

The standards UNE-EN 1341, UNE-EN 1469, UNE-EN 12057 and UNE-EN 12058 establish the dimensional tolerances or maximum permissible deviations for natural stone tiles and slabs. These tolerances can be considered mandatory as they are implicit in the factory production control, which forms part of the conformity assessment systems defined in annexes Z of the standards.

Standard UNE-EN 12825 establishes different dimensional tolerances for raised access floor tiles, which are to be considered voluntary, since the standard does not include Annex Z and, therefore, raised access floor tiles or their components do not have a specific CE marking.

In the declaration of performance and the CE marking, the dimensional class must also be declared when this is established in the applicable standard. The technical specifications must specify the standard and the dimensional class and may require more stringent tolerances.

Depending on the standard adopted, the tolerances may be strict. UNE-EN 1341 applies to outdoor paving only, specifically pavements, squares,

and roadways with vehicular traffic. For these applications, large formats (up to 1 m2) are usually used, with high thickness (between 30 and 100 mm) with a coarse surface texture (bush-hammered, flamed, etc.).

On the other hand, the UNE-EN 1469, UNE-EN 12057 and UNE-EN 12058 standards apply to both indoor and outdoor flooring and cladding. For these applications, medium-sized formats (up to 0.36 m2), thin (10 to 30 mm) and both fine finishes indoors (especially polished) and coarse textured finishes outdoors are common.

These differences in terms of formats and finishes justify the fact that the dimensional tolerances required in the UNE-EN 1469, UNE-EN 12057 and UNE-EN 12058 standards are more demanding than in the UNE-EN 1341 standard.

As for the dimensional tolerances required by standard UNE-EN 12825 for recordable raised floor tiles, they are even more demanding than those established by UNE-EN 12057 and UNE-EN 12058, probably because they are not specifically designed for natural stone products, in which the industry is not capable of supplying such precise dimensioning.

The following tables show the tolerances set by the different harmonised standards, grouped for each dimensional characteristic, to facilitate their comparison[29]:

UNE-EN 134 (external paving)				
Edges or corners	Sawed		Split or carved	
P0 class	no requirement			
P1 class	±4mm		±10mm	
P2 class	±2mm		±10mm	
UNE-EN 12058 (indoor/outdoor flooring) and UNE-EN 1469 (indoor/outdoor cladding).			UNE-EN 12057 (indoor/outdoor floor and wall cladding)	
Nominal length or width	<600mm	≥600mm	Class	Tolerance
Thickness ≤50mm	±1mm	±1,5mm	Uncalibrated platelets	±1,5mm
Thickness >50mm	±2mm	±3mm	Calibrated platelets	±0,5mm
UNE-EN 12825 (regisratable raised floors)				
Class	Class 1		Class 2	
Tolerance	±0,2mm		±0,4mm	

Table 3: Tolerances for floor plan dimensions

UNE-EN 1341 (outdoor flooring)					
Thickness, T (mm)	T ≤ 30	30 < T ≤ 80		T > 80	
T0 class	no requirement				
T1 class	±3mm	±4mm		±7mm	
T2 class	±10%	±3mm		±4mm	
UNE-EN 12058 (indoor/outdoor flooring) and UNE-EN 1469 (indoor/outdoor cladding).					
Thickness, T (mm)		12 < T ≤ 15	15 < T ≤ 30	30 < T ≤ 80	E > 80
UNE-EN 22058:2005	Tolerance	±1,5mm	±10%	±3mm	±5mm
UNE-EN 12058:2015		±10%		±3mm	±5mm
UNE-EN 1469					
UNE-EN 12057 (indoor/outdoor floor and wall cladding)					
Class	Uncalibrated platelets		Calibrated platelets		
Tolerance	±1,5mm		±0,5mm		
UNE-EN 12825 (regisratable raised floors)					
Class	Class 1		Class 2		
Tolerance	±0,3mm		±0,5mm		

Table 4: Thickness tolerances

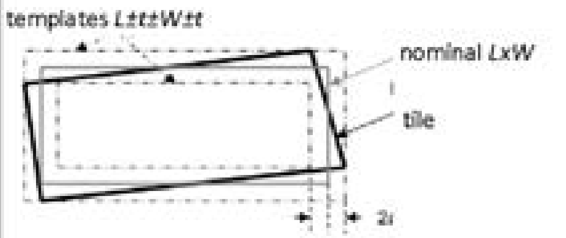
UNE-EN 1341 (outdoor flooring)				
Difference between diagonals		Serrated edges		Split or carved edges
D0 class		no requirement		
D1 class		±6mm		±15mm
D2 class		±3mm		±10mm
UNE-EN 12058 (indoor/outdoor flooring) and UNE-EN 1469 (indoor/outdoor cladding).				
Nominal length or width			<600	≥600mm
UNE-EN 12058	Tolerance (t)	Thickness ≤50mm	±1mm	±2mm
		Thickness >50mm	±1,5mm	±3mm
UNE-EN 1469			±1mm	±2mm
The perimeter of the stone must be inside the area constituted by two concentric templates and separated by a distance of ±t from the reference nominal.				
UNE-EN 12057 (indoor/outdoor floor and wall cladding)				
Class		Uncalibrated platelets		Calibrated platelets
Squareness or orthogonality tolerance		±0,15%		±0,10%
UNE-EN 12825 (regisratable raised floors)				
Class		Class 1		Class 2
Squareness or orthogonality tolerance		±0,3mm		±0,5mm

Table 5: Tolerances for angles

UNE-EN 1341 (outdoor flooring)				
Length of longest straight centre		0,5m	1m	1,5m
Tolerance	Fine texture	±2mm	±3mm	±4mm
	Coarse texture	±3mm	±4mm	±6mm
UNE-EN 12825 (regisratable raised floors)				
Class	Class 1		Class 2	
Tolerance	±0,3mm		±0,5mm	

Table 6: Tolerances for edges straightness

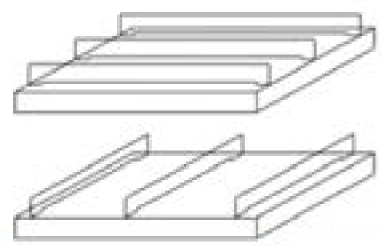
UNE-EN 1341 (outdoor flooring)						
Lift length (mm)			300	500	800	1000
Vertical faces	Thickness ≤ 80mm		±12mm			
	Thickness > 80mm		±15mm			
Horizontal faces	Convexity	Coarse texture	±3mm	±4mm	±5mm	±8mm
		Fine texture	±2mm	±3mm	±4mm	±5mm
	Concavity	Coarse texture	±2mm	±3mm	±4mm	±6mm
		Fine texture	±1mm	±2mm	±3mm	±4mm
UNE-EN 12058 (indoor/outdoor flooring) and UNE-EN 1469 (indoor/outdoor cladding).						
Sight side	Exfoliated or split		Finished or worked			
Tolerance	no requirement		0.2% of the evaluation length and ±3mm			
Example of 6 evaluation sections parallel to edges						
UNE-EN 12057 (indoor/outdoor floor and wall cladding)						
Class			Uncalibrated platelets		Calibrated platelets	
Flatness tolerance (fair face)			±0,15%		±0,10%	
UNE-EN 12825 (regisratable raised floors)						
Class			Class 1		Class 2	
Warp tolerance			±0,5mm		±0,7mm	
Concavity tolerance			±0,3mm		±0,6mm	

Table 7: Tolerances for flatness

2.2.2 Real density and apparent density, and of total and open porosity

Porosity and density of natural stones may be measured by a variety of test methods, as those described in the relevant ISRM suggested method[30]. Usually, they are determined by the buoyancy method, where the mass of a single specimen is measured when it is completely dry, saturated in the air, and saturated and immersed in the water. The volume of the open pores is determined by the masses difference between the saturated and the dried specimen, divided by the density of water. The bulk volume is determined by the masses difference between the saturated specimen in the air and when immersed. Then, open porosity is determined as the percentage of the pore's volume divided by the bulk volume of the specimen. Density of the specimen is determined by the ratio of its mass divided by its volume.

Care should be paid during saturation of the specimen, where saturation under vacuum is commonly achieved. It should be noted that with this method, only the open porosity is saturated and thus determined.

In Europe, porosity and density of the natural stone should be determined according to the European Standard EN 1936[31]. In the same standard, procedures for determining the total porosity of the specimen are also provided, where the specimen needs to be fully pulverized.

Objective
Determination of the apparent density and open porosity. Deduction of its hygrometric and acoustic insulation properties and determination of the weight of the construction element itself.

Scope
This test is applied to natural stone (marble, limestone, granite, slate, sandstone, etc.) for use as dimensioned pieces in construction. Its declaration by the manufacturer is considered compulsory for interior flooring and cladding, both exterior and interior, as it constitutes an essential characteristic in annexes Z of standards UNE-EN 1469, UNE-EN 12057 and UNE-EN 12058 and therefore forms part of the information in the declaration of performance and the CE marking.

Reference documents
UNE-EN 1936:2006. "Natural stone test methods. Determination of real density and apparent density, and of total and open porosity".

Method
The systematic to be applied for carrying out the tests is the one established in the European standard UNE-EN 1936.

Preferably cubic specimens of 50x50x50 mm shall be used.

Video 1: Vacuum start-up. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Video 2: Weighed by removing excess water with a cloth. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Video 3: Hydrostatic weighing. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

2.2.3 Determination of water absorption at atmospheric pressure

Water absorption of natural stone is determined by firstly drying the stone specimens to constant mass and then soaking of the specimens in the water for a fixed period of time. Water absorption is calculated as the ratio of the masses deference of the dry and the saturated specimen to the mass of the dry specimen and it is expressed as a percentage. Detailed procedures to be followed are provided in the EN 13755[32].

2.2.3.1 Objective

Determination of water absorption of a rock sample under pressure conditions of 1 atmosphere. It is determined as the percentage by weight of water that the rock is capable of absorbing.

2.2.3.2 Scope

This test applies to natural stone (marbles, limestones, granites, slates, sandstones, etc.) for use as dimensioned parts in construction.
Reference documents

UNE-EN 13755:2008: “Natural stone test methods. Determination of water absorption at atmospheric pressure”.

2.2.3.3 Method

The systematic to be applied for carrying out the tests is the one established in the European standard UNE-EN 13755.

Preferably, cubic specimens of 50x50x50 mm shall be used.

The specimens shall be placed in a cuvette and shall be flooded according to the standard. Demineralised water shall be used for immersion. During immersion of the test pieces in water, the temperature of the water shall be checked periodically with a mercury thermometer. The temperature of the water shall be kept stabilised at 20±10 °C by controlling the air conditioning of the room and by adding cold or hot water, as appropriate.

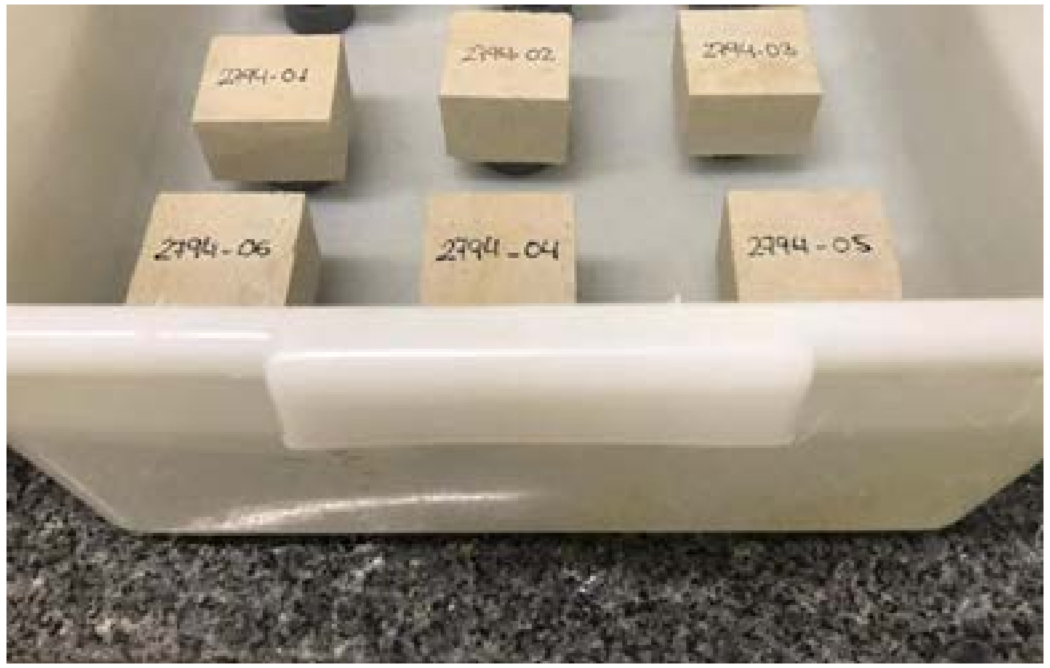


Figure 17: Test specimens. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The weighing shall be carried out on a balance with a resolution of 0,001 g. The wet weighing shall be carried out after removing any surface water observed on the test tube with a cloth.

Figure 18: Removal of excess water. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

2.2.4 Determination of water absorption coefficient by capillarity

Another method to measure water absorption[33] utilizes the capillary absorption ability of the natural stone by placing the base of the specimen in a few millimeters of water. The water moves to the natural stone specimen by capillary suction, through its pores and pre-existing cracks. The procedures and methods to be followed are given in EN 1925[34] standard.

2.2.4.1 Objective

Determination of the capillary water absorption coefficient.

2.2.4.2 Scope

This test applies to natural stone for ornamental purposes whose open porosity is approximately equal to or greater than 1% such as limestone and sandstone. According to UNE-EN 1469, UNE-EN 12057 and UNE-EN 12058, this characteristic may be of interest, for example, in elements placed in contact with a horizontal surface that may contain water (e.g. pavements, terraces, cornices, showers, etc.).

2.2.4.3 Reference documents

UNE-EN 1925:1999. "Natural stone test methods. Determination of water absorption coefficient by capillarity".

2.2.4.4 Method

The systematic to be applied for carrying out the tests is that established in the European standard UNE-EN 1925:1999.

After drying the specimens at 70±5 °C until constant mass, the absorption coefficient is determined.

The test is preferably carried out on 70x70x70mm specimens. After drying and subsequent acclimatisation to room temperature, the bases that will be in contact with the water of each of the specimens are measured with a caliper gauge.

The specimens shall be introduced sequentially, so that the weighing times of the different specimens do not coincide, always following the indications of the standard. When the first specimen is immersed, the chronometer is started.

The test specimens are placed in the distilled water tank on perfectly measured supports as indicated in the standard. The water level is checked by means of a gauge at the base of the cuvette.

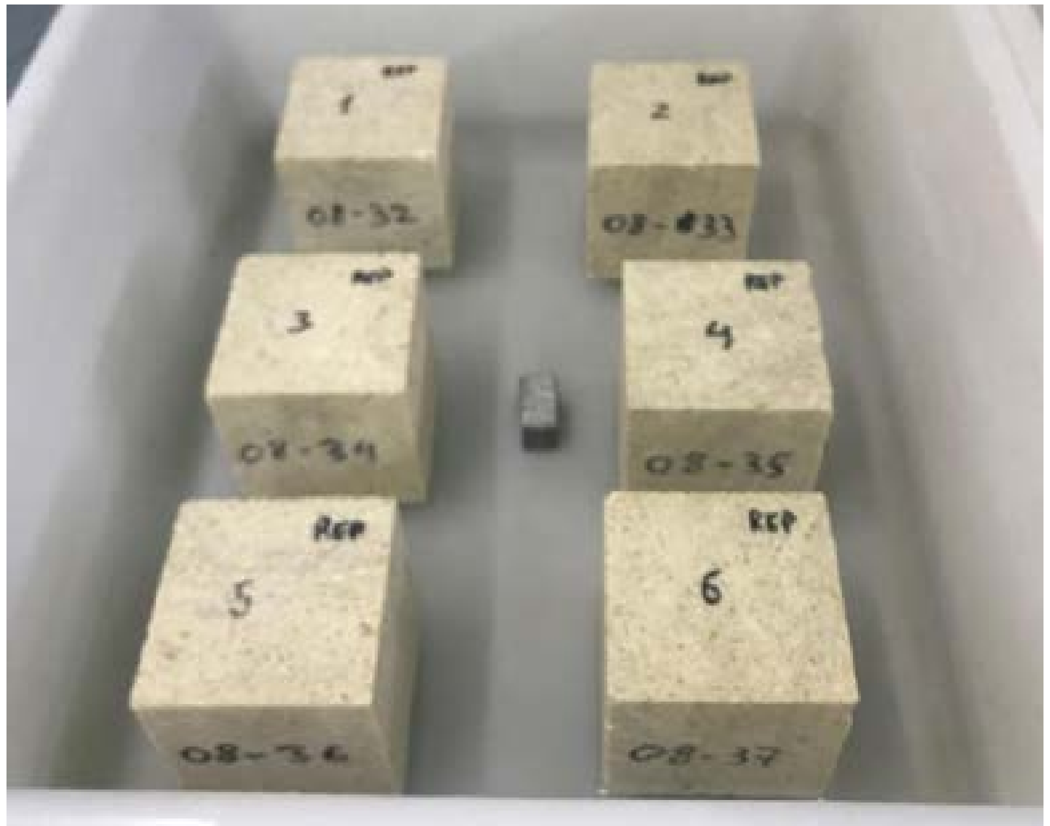


Figure 19: Specimens at the end of the test and control piece. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

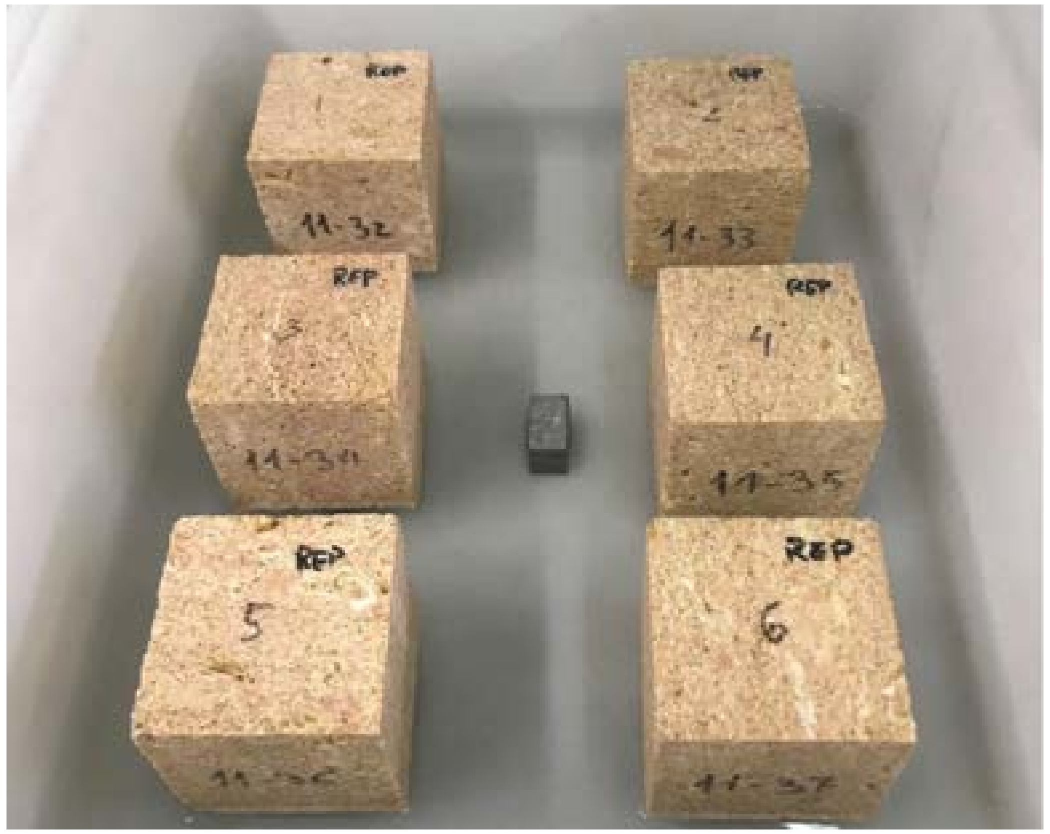


Figure 20: Specimens at the end of the test and control piece. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Testing of mechanical properties of building materials

3.1 Abrasion resistance

The abrasion resistance of natural stones that are used in paving or floor cladding applications is determined by abrasion of a specimen by a wheel of a disk of an abrasive material. Commonly used test methods are the wide-wheel or Capon, the Bohme[35] and the Amsler test methods[36]. Although the test provides an indication of the natural stone wear, interpretation of the test results to yield absolute abrasion values for practical applications is rather difficult.

The procedures to be followed for abrasion resistance testing of natural stones are given in the European standard EN14157[37].

3.1.1. Objective

Determination of abrasion resistance of natural stone used for paving in buildings. Abrasion resistance is the only standardised characteristic for natural stone at European level, which allows estimating the behaviour of the rough surface of a pavement, which is going to be exposed to wear by pedestrian use or road traffic, so that in a way it gives us a measure of the durability of the non-slip finish of the pavements.

3.1.2. Scope

This test applies to natural stone products for use as paving in building construction.

3.1.3. Reference documents

UNE-EN 14157:2018. “Natural stone test methods - Determination of the abrasion resistance”.

3.1.4. Method

The systematic to be applied for carrying out the tests is the one established in the European standard UNE-EN 14157.

The test shall preferably be carried out on 150x150x30mm polished specimens. As a minimum, they must measure 100x70mm.

The abrasion machine must comply with the stipulations of the UNE-EN 10025 standard. The hardness of the steel must be between 203 HB and 245 HB. Its diameter must be 200±1mm and its width 70±1mm.

The specimens must be clean and dry at 70±5°C until constant mass. If the specimen to be tested has impurities, they shall be removed before starting the test.

The abrasive is introduced into the hopper. After this, the test tube is placed on the test tube trolley.

Video 4: Test tube placement and abrasion process. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The specimen is placed in contact with the wide abrasive disc, the valve is opened and the engine is started.

Where possible, two tests shall be carried out on each test piece.

To measure the footprints, a two-magnification magnifying glass shall be used and it shall be done as indicated in the UNE-EN 14157:2018 standard.

Video 5: Footprint measurement. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The result is the dimension corrected by the calibration factor. The result of this test is expressed in mm of the width of the footprint with 0,5 mm of approximation, being therefore a comparative value with the Boulonnais marble. The deeper the penetration of the disc into the tile, the lower the resistance of the stone to wear, and the larger the mark, if two marks are made, the higher the result selected.

The calibration factor is understood to be the abrasimeter calibration factor value in force.

3.2 Slip resistance

Slipperiness of natural stones when used in paving or flowing applications is assessed by the slip resistance test. The most usual method is the pendulum test method[38], from which the pendulum test value (PTV) is evaluated, as a measure of the friction between the stone surface and the slider on the pendulum arm. Test procedures and methods to assess the slip resistance of natural stone in Europe are provided in the European standard EN 14231[39].

3.2.1 Objective

Determination of slip/slip resistance of unpolished and polished pavement units.

3.2.2 Scope

This test applies to any product for use as flooring (tiles, steps, paving slabs, cobblestones, etc.) or elements that can be walked on by people (shower trays, swimming pool slabs, etc.).

It is compulsory to be declared by the manufacturer for natural stone tiles for outdoor use including the finishing of roadways for pedestrian or vehicular traffic (UNE-EN 1341 Annex ZA), and for natural stone tiles for pedestrian use in indoor or outdoor areas (UNE-EN 12057 Annex ZA and UNE-EN 12058 Annex ZA).

3.2.3 Reference documents

UNE-EN 14231:2004. “Natural stone test methods. Determination of the slip resistance by means of the pendulum tester”.

3.2.4 Method

The system to be applied for carrying out the tests is that established in European standard UNE-EN 14231:2004.

Preferably, 300x300mm tiles shall be used, a minimum of 3 tiles. On each

of the tiles, two representative surfaces of 136x86mm parallel to the edges and oriented perpendicularly to each other shall be selected and marked with an indelible marker pen without the need to cut them.

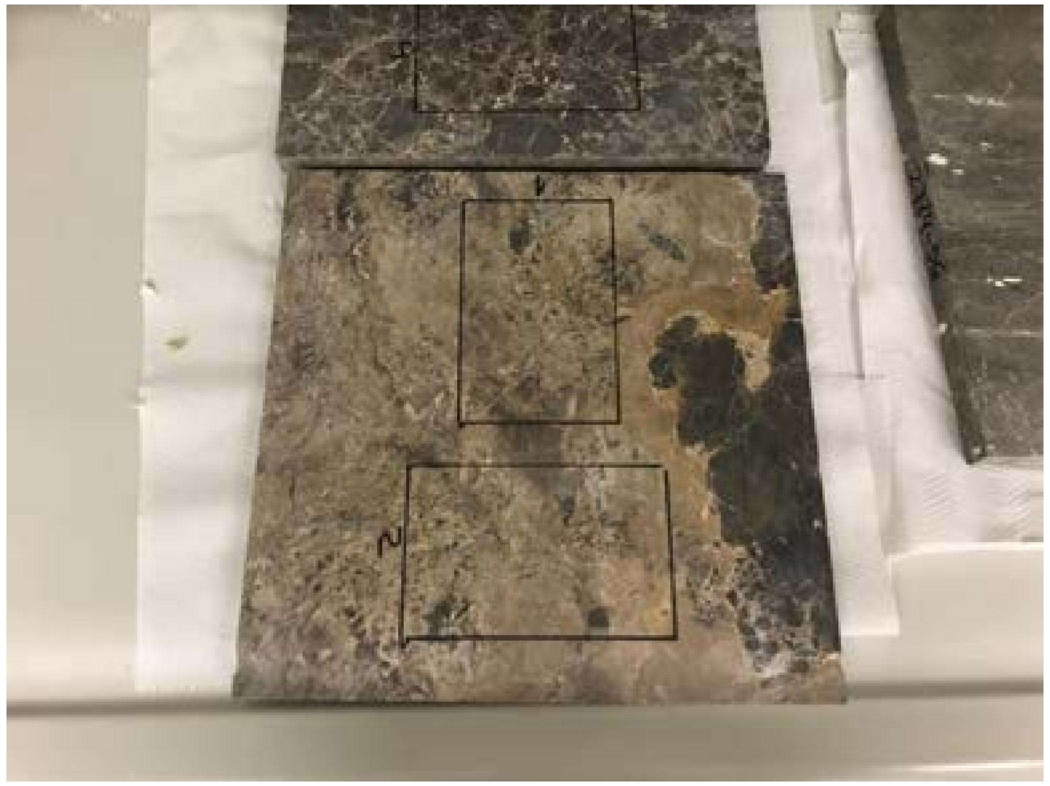


Figure 21: Marked specimens. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The measuring equipment consists of a pendulum, the arm of which supports a rubber slider of hardness IRHD = 57 (similar to the rubber used in the most common shoe soles), to which a constant load of 22 N is applied. As it oscillates, the slider rubs against the tested surface during a 126 mm travel, with an average angle of 26°, rubbing through one of its edges of 76 mm, slightly bevelled. By measuring the difference between the initial height and the height reached by the arm after friction, a dynamic friction coefficient value is obtained. The test is carried out both wet, i.e. on wet tiles, and dry.

The friction pendulum and the test specimens must be at 20±2°C for at least 30 min before the test is carried out.

When the wet test is to be carried out, immediately before the test, the test piece shall be immersed in water for at least 30 minutes.

Before each test or series of tests, the following shall be checked:

1. The horizontality of the surface where the test is carried out with a level.
2. The adjustment of the drive screw of the indicating pointer.
3. The wear and wear-out of the shoe, by measuring with a caliper.
4 The alignment of the pendulum arm with the equipment.
5. That the temperature is maintained at 20±2°C.
6. That the indicator handpiece marks the zero with free oscillation.
7. That the trajectory of the shoe is aligned with the surface edges of the test..

When the test is carried out in wet conditions, before each new oscillation, the test surface of the test specimen and the test shoe shall be thoroughly wetted with demineralised water by spraying.

Video 6: Slip resistant. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

3.3 Uniaxial compressive strength

Compressive strength of natural stones[40] is determined by subjecting cubic, prismatic, or cylindrical stone specimens in uniaxial compressive loading and measuring the maximum load that the specimen can resist during the test[41,42]. The ratio of the maximum load to the cross section of the specimen is the uniaxial compressive strength. Several suggested methods and standards are available for this test. In terms of engineering design, the ISRM suggested method (Figure 20) is the most used method for compressive strength determination.

Usually in depth analyses the natural stone samples will be taken from the source using the usually methods and prepared for testing in laboratory, presented in fig 22.

Figure 22: Testing of a cylindrical stone specimen according to the ISRM test method

Figure 23: Testing of a cylindrical stone specimen according to the ISRM test method

The relevant European standard for compressive strength determination of natural stones is the EN 1926[43].

Testing according to this standard requires either cubic specimens, such as this shown in Figure 22, or cylindrical specimens of equal height and diameter.

Objective

Determination of the mechanical resistance of natural stone to uniaxial compression.

Scope

This procedure is applied to natural stone (marbles, limestones, granites, slates, sandstones, etc.) for use as dimensioned parts in construction.

Reference documents

UNE-EN 1926:2007: “Natural Stone Test Methods. Uniaxial compressive strength”.

Method

Specimen format: cubes with an edge of 50 to 70±5 mm. The maximum difference shall be 5 mm between the 3 axes. They can also be cylinders with a height and diameter of 50 to 70±5 mm with a maximum difference of 5 mm between height and average diameter. If irregularities are present, they shall be removed by hand polishing and checked for flatness.

The orthogonality of the bases and side faces can be checked by means of a goniometer. The specimen shall be rejected if the deviation from the right angle exceeds 1%.

At least 10 specimens shall be tested. All specimens shall be conditioned and dried to constant mass (dried to 70 ± 5 °C). They are left at room temperature and shall be tested within 24 hours.

Before the specimen is placed in the press, any particles on the top and bottom of the specimen and the press shall be cleaned off.

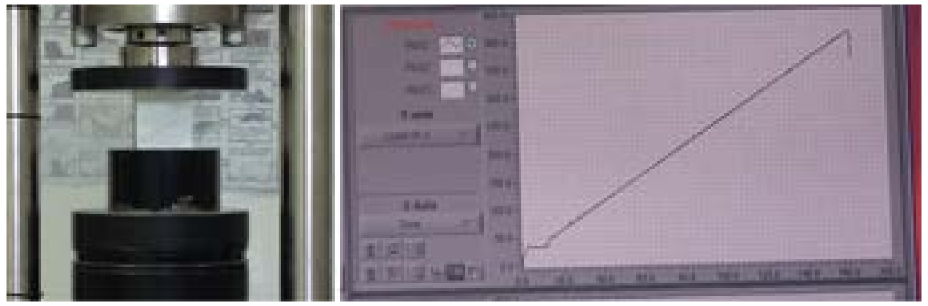


Figure 24: Testing of a cubic stone specimen according to the EN test method and continuous recording of the applied compressive load.

The specimen shall be subjected to a load, applied continuously with a compression rate of (1±5)MPa/s.

3.4 Determination of flexural strength under concentrated load

The test is performed on beam specimens supported by two bearings and loaded transversely by one or two point loads. In the first case the test is referred to as a three-point test, while in the second as a four-point test. The four-point test introduces a constant bending moment between the loading points, while in the three-point test the maximum bending moment is exerted in the middle of the specimen.

For the execution of the bending test and the estimation of the flexural strength of the stone there is no method suggested by the ISRM. The test is generally performed on prismatic specimens of rectangular cross section. European standard EN 12372[44] prescribes the use of the three-point bending test in prismatic stone specimens.

3.3.1 Objective

Determination of bending strength under concentrated load. The mechanical behaviour of the slabs or tiles depends mainly on this property.

3.3.2 Scope

This test applies to natural stone (marbles, limestones, granites, slates, sandstones, etc.) for use as dimensioned parts in construction.

3.3.3 Reference documents

UNE-EN 12372:2007. "Natural stone test methods. Determination of flexural strength under concentrated load".
UNE-EN 13161:2008. "Natural stone test methods. Determination of flexural strength under constant moment".

3.3.4 Method

The system to be applied for carrying out the tests is that established in the European standard UNE-EN 12372 and UNE-EN 13161. The sample shall be tested, preferably formed by the three whole slabs or tiles or, failing that, by three pieces (as large as possible) each cut from a different slab or tile. The bending strength test under concentrated load according to UNE-EN 12372 shall be carried out, or in the case of rocks with significant discontinuities (joints, laminations, etc.) or coarse grain size, the constant moment bending strength test according to UNE-EN 13161 shall be carried out, which provides more reliable results in heterogeneous rocks.

The test shall preferably be carried out on 300x50x50mm specimens. For other formats, the thickness h must be between 25 and 100mm and must be greater than twice the size of the largest crystal of the stone; the total length L must be equal to six times the thickness; the distance between the support rollers l must be equal to five times the thickness; the width b must be between 50mm and 3 times the thickness. The dimensions of the specimens shall be checked with a caliper gauge and shall not differ from one end to the other by more than 1 mm.

At least 10 specimens are selected, the surface of which must be dried to constant mass at 70±5ºC. After drying, they shall be stored at 20±5ºC and tested within 24 hours.

If the stone shows planes of anisotropy the specimens have to be placed according to at least one of the arrangements marked by the standard and at least two parallel lines shall be marked on each specimen. The specimen is carefully aligned and centred between the rollers.

Figure 25: Placing the specimen in the press. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The load shall be increased uniformly from 0.25±0.05 MPa/s until failure. With this value, the flexural strength shall be calculated as indicated in the standard.

Video 7: Flexural strength under concentrated loading. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The result shall be considered favourable when the individual results of the three slabs or tiles are higher than the value specified in the project for the flexural strength. In the event that one of the three slabs or tiles gives a negative result, the test shall be repeated with three other slabs or tiles, the result of this second test being accepted if favourable.

3.5 Determination of the dynamic modulus of elasticity.

The modulus of elasticity of the natural stones is measured under uniaxial compression of cylindrical stone specimens. According to the ISRM suggested method[45], the axial strains are measured at the mid-height of the specimen and the modulus of elasticity is calculated at the slope of the more or less linear part of the stress-strain curve during the test.

In the European standard EN 14580[46] for the static modulus of elasticity determination, the use of cylindrical stone specimens is also prescribed. However, the elastic modulus is evaluated as a secant modulus between a lower and an upper stress level, which are defined with respect to the uniaxial compressive strength of the stone measured according to EN 1926.

Video 8: Measurement of the frequency of the specimens. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

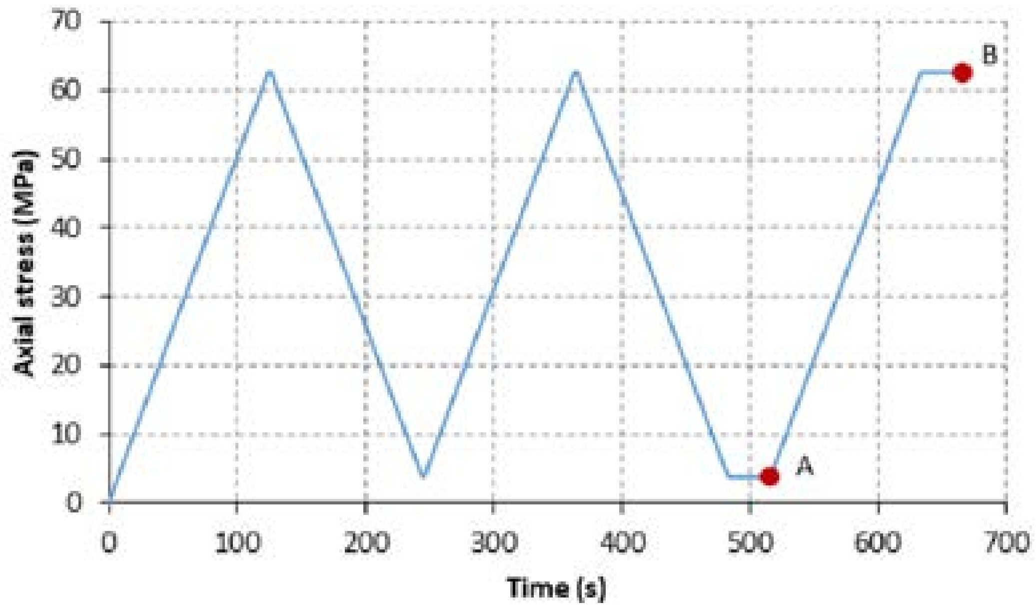


Figure 26: Indicative diagram of axial stress versus time for the determination of the static modulus of elasticity according to the EN 14580 standard.

3.6 Determination of the dynamic modulus of elasticity.

Objective

Determination of frost resistance of natural stone by freezing cycles in air and thawing in water.

Scope

This test applies to natural stone (marbles, limestones, granites, slates, sandstones, etc.) for use as dimensioned parts in construction.

Reference documents

UNE-EN 1926:2007. "Natural Stone Test Methods. Uniaxial compressive strength".
UNE-EN 12371:2011. "Natural stone test methods. Determination of frost resistance".
UNE-EN 12372:2007. "Natural stone test methods. Determination of flexural strength under concentrated load".
UNE-EN 13364:2002. "Natural stone test methods. Determination of breaking load at dowel hole".
UNE-EN 14146:2004. "Natural stone test methods. Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency)".

Method

The system to be applied for carrying out the tests is that established in the European standard UNE-EN 12371.

The freeze-thaw cycles are always carried out at the same temperatures, respecting the limits set by the standard. As many cycles as the client wishes or until two specimens are altered. According to the test standard UNE-EN 12371, the freezing temperatures applied in the tests do not fall below -12°C, which raises controversy about its validity in regions with lower temperatures. However, it should be noted that below this temperature, the increase in volume within the pores is negligible.

Specimens shall be used according to the test to be carried out and its respective standard.

The specimens shall be dried to constant mass at a temperature of 70±5°C.

TECHNOLOGICAL TEST. The corresponding standards are UNE-EN 12372 or UNE-EN 13161 for bending strength, UNE-EN 13364 for anchor breaking load, UNE-EN 14066 for thermal shock resistance and UNE-EN 1926 for compressive strength.

The average decrease in bending strength shall be expressed as a percentage of the average value of the bending strength of the batch not subjected to freeze-thaw cycles as well as anchorage strength and compressive strength. In the case of using the value of the decrease in flexural strength, the standards UNE-EN 12057 and UNE-EN 12058 state that a decrease of less than 20% should not be considered significant. This limit is not normative and should not be interpreted to mean that variations of more than 20% imply deterioration or frost damage.

IDENTIFICATION TEST. The test specimens shall be rectangular prisms of 50x50x300 mm.

Initial defects and all irregularities must be marked with indelible markers. In addition, to ensure that measurements are made on the same points of the specimens.

The initial immersion of the test specimens is carried out at 20±5 °C. They must be at least 15 mm apart. After 60±5 min, running water is added until three quarters is reached and after 120±5 min after the first flooding, water is added until the specimens are submerged under a sheet of 25±5mm of water.

Video 9: Initial hygrometric weighing. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

After this, the test pieces shall be placed in the climatic chamber without touching each other or the chamber walls. Every 14 cycles the test pieces shall be rotated 180° and visual inspections shall be carried out.

Video 10: Visual inspection of specimens. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The identification test determines, in accordance with UNE-EN 12371, the number of cycles endured (Nc) by the rock before failure, using one of the following 2 evaluation criteria, the one that allows the failure to be appreciated first:

- Classification by visual inspection of 2 or more pieces from a sample of at least 6 pieces, reaches grade 3 on the following scale:

- Grade 1: minimal damage (minimal rounding of corners and edges) which does not compromise the integrity of the piece.

- Grade 2: one or more small cracks (≤ 0.1 mm wide) or breakage of small fragments (≤ 30 mm2, per fragment).

- Grade 3: one or more cracks, holes or breakage of fragments larger than that defined in grade 2, or an alteration of the material into streaks; or the specimen shows significant signs of disaggregation or dissolution; - Grade 4: specimen with large cracks or broken into two or more pieces or disintegrated.

- Grade 4: The dynamic modulus of elasticity suffers a decrease ≥ 30% in 2 or more pieces of a specimen of at least 6 pieces.

In the case of no failure, the test continues up to the number of cycles requested from the laboratory, whereby Nc is equal to the number of cycles requested. The maximum number foreseen for the identification test in the UNE-EN 12371 standard is 168 cycles.

After completing the number of cycles, the specimens shall be tested according to the corresponding standard.

3.7 Determination of breaking load at dowel hole.

Objective
Determination of breaking load resistance by anchorages.

Scope
This test applies to natural stone for ornamental purposes (marbles, limestones, granites, slates, sandstones, etc.). The breaking load test for anchors is specific to cladding slabs for ventilated facades.

Reference documents
UNE-EN 13364:2002. “Natural stone test methods. Determination of breaking load at dowel hole”.

Method
The testing system to be applied is the one established in the European standard UNE-EN 13364:2002.

Whenever possible, 10 specimens shall be used, both in type 0/I tests and in type II tests. In the type 0/I tests, we shall have one perforation per specimen and in the type II tests, 2 perforations shall be made per specimen in two of its perpendicular edges.

The drill holes in the test specimens shall be made with progressively sized drill bits, leaving a pause between each hole to allow for cooling.

At each start-up, a load increase rate of 50N/s shall be applied.

3.8 Salt crystallization

Objective

Determination of the resistance of natural stone to crystallisation of sodium sulphate decahydrate.

Scope

This procedure applies to natural stone with an open porosity of approximately 5% or more (limestones, sandstones, etc.) for use as dimensioned parts in construction.

Reference documents

UNE-EN 12370:2020: “Natural stone test methods. Determination of resistance to salt crystallisation”.

Method

Specimen format: 40x40x40±1mm.
Firstly, the specimens are washed and dried to constant weight.
It is determined by the method of the UNE-EN 12370 standard, by which the stone sample is subjected to a maximum of 15 cycles, each one consisting of 2 h of immersion at 20 ± 0.5°C in a saturated solution of Na2SO4-10H2O, followed by 16 h of progressive heating in air with high humidity, up to 105 ± 5°C. Photographs shall be taken at the beginning and at the end of the test.

Video 13: Preparation of the solution. (Source: Centro Tecnológico del Mármol, Piedra y Materiales) 1º video 3º video 2º video

The necessary volume of solution to be prepared is calculated knowing that the density must be 1055kg/m3 and that the test tubes must be covered by 8±2mm of solution. The solution has to be prepared with demineralised water and the solution has to be prepared at least 2 hours before immersion and at 20±0,5°C.

Figure 28: Density check. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The necessary volume of solution to be prepared is calculated knowing that the density must be 1055kg/m3 and that the test tubes must be covered by 8±2mm of solution. The solution has to be prepared with demineralised water and the solution has to be prepared at least 2 hours before immersion and at 20±0,5°C.

Video 14: Immersion of test specimens. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

At the end of the immersion period, the test pieces shall be removed from the solution and placed in the climatic chamber.

FIgure 29: Wet specimens after 2 hours of immersion. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

The chamber shall be heated progressively for 12h 30’ from 20 to 105ºC, without humidity control. After the heating section, the temperature of 105ºC shall be maintained for 3h 30’ until the chamber is stopped for 16h. The chamber door shall then be opened to allow the specimens to cool for 5.30 hours to room temperature.

Figure 30: Wet specimens after 2 hours of immersion. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Half an hour before immersion, the chamber door shall be closed again, with the test tubes inside, and the chamber shall be started so that 20ºC is reached at the time of immersion. The sequence described above completes 24 hours and is repeated cycle after cycle.

The crystallisation of the salt in the pores during the heating period tends to produce detachment of particles, rounding of edges and finally breakage or disintegration of the specimens. The result is expressed as the number of cycles required to cause destruction, or as the mass loss (%) after 15 cycles.

After 15 cycles, the specimens are weighed on a balance.
When a specimen loses more than 25 per cent of its mass, the specimen is not further tested.

Video 15: Weighing. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

3.9 Determination of resistance to ageing by thermal shock.

Objective
Determination of resistance to ageing due to thermal shock according to UNE EN 14066 and of sensitivity to changes in appearance caused by thermal cycles according to UNE EN 16140.

Scope
This test is applied to natural stone (marble, limestone, granite, slate, sandstone, etc.) for use as dimensioned stone in construction.

The resistance to thermal shock allows the estimation of the durability of exterior paving and cladding exposed to the effect of atmospheric agents, particularly the effect of humidity and temperature changes.
Reference documents

UNE-EN 14066:2014. “Natural stone test methods. Determination of resistance to ageing by thermal shock”.
UNE-EN 14146:2004. “Natural stone test methods - Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency).

Method
The system to be applied for carrying out the tests is that established in the European standard UNE-EN 14066:2014.

The dimensions of the specimens must comply with standard EN 12372, i.e. determined by their thickness.

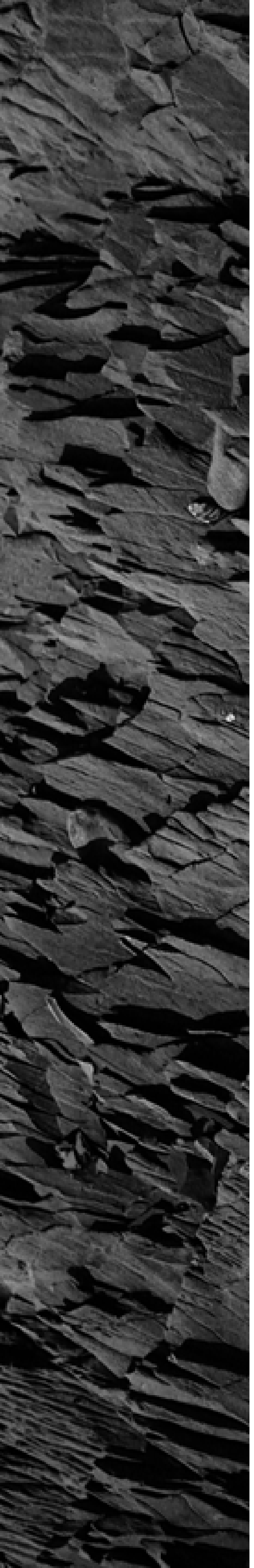
- The thickness must be between 25mm and 100mm and must be more than twice the largest grain size of the stone.
-The length must be equal to six times the thickness.
-The distance between support rollers must be equal to five times the thickness.
-The width must be between 50mm and three times the thickness, and in no case must it be less than the thickness.

Preferably, specimens of 300x50x50mm shall be used.

Prior to the start of the cycles, the imperfections of the specimens shall be marked with indelible ink. In addition, to ensure that the frequency measurement is carried out at the same points, indelible ink marks shall also be made on the faces of the specimens to indicate the location of the emitter and receiver and the central axis.

After drying the specimens at 40±5 °C to constant mass, the specimens are subjected to successive cycles, each cycle consisting of drying at 70±5 °C (18±1 hours) followed immediately by immersion in water at 20±5 °C (6±0.5 hours).

Figure 32: Introduction of the specimens into the oven. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)



After the 20 cycles, the specimens are dried at 70±5°C until constant mass and are visually inspected, recording any alterations.

The non-destructive tests are carried out first, such as the open porosity according to UNE-EN 1936, the measurement of sound propagation according to UNE-EN 14579 or the measurement of the dynamic modulus of elasticity according to UNE-EN 14146. Comparing the data with those initially obtained.

Finally, the bending test is carried out, the data of which are compared with those of other dry reference specimens without being subjected to the 20 cycles of thermal shock.

3.9.5 Essential requirements for natural stone products

Natural stones are quarried for the initial purpose of acquiring blocks or slabs that meet specific specifications in terms of their dimensions and shape. In addition, the usual requirements for the various applications are related to the color, texture and finish of the surface of the natural stone. The criteria for selecting a natural rock for a specific application may include properties such as dur bility, which depends on the mineralogical composition and hardness of the minerals, compressive and flexural strength, as well as its susceptibility to polishing the surface by the various machining methods[47].

Today, the requirements regarding the physical and mechanical properties of natural stones[48] for various applications are determined by national or international regulations. The meticulous application of the regulations[49] is necessary for the proper use of a natural stone, both with a view to safety and with a view to minimizing costs. If a natural stone does not meet the specifications for a particular application, then the maintenance cost increases the total cost of the application, but safety issues are also raised during use, such as the increased slipperiness of a floor, or the failure of a natural stone on a lintel[50].

In Europe, the specifications for the requirements for the properties of natural stones are determined by European norms[51,52]. Table 3 summarizes the available European norms that include requirements for various applications.

Category	Norm	Short Description
General	EN 12670 : Natural stone – Terminology	Terminology of scientific and technical terms, test methods, products and classification of natural stones
	EN 12440: Natural stone – Denomination criteria	Sets out the criteria for the characterization of natural stone from raw material to final products
Rough blocks and slabs	EN 1467: Natural stone – Rough blocks – Requirements	Specifies the requirements for raw natural stone blocks intended for the manufacture of natural stone products
	EN 1468: Natural stone – Rough slabs – Requirements	Determines the requirements for raw slate slabs for the manufacture of building products or other similar applications
Final products	EN 1469: Natural stone products – Slabs for cladding – Requirements	Specifies the requirements for natural stone slabs intended for use as a lining for finishing of interior and exterior walls and ceiling.
	EN 12058: Natural stone products – Slabs for floors and stairs – Requirements	Specifies the requirements for flat slabs of natural stones intended for use as floor and stair linings.
	EN 12059: Natural stone products – Dimensional stone work – Requirements	Specifies the requirements for building blocks of natural stones such as bearing stone elements (e.g. solid columns), structural elements for bras and railings, as well as panels of natural stones for the exterior finishing of walls and columns, footrests, archieves and others.
	EN 1341: Slabs of natural stone for external paving – Requirements and test methods	Specifies the requirements regarding the performance and the test methods of natural stone slabs for external paving (typical road pavements, outdoor squares and outdoor areas, etc.) and road finishes (traffic areas), the assessment of conformity and their marking, and characteristics that are important for the trade.
	EN 1342: Setts of natural stone for external paving – requirements and test methods	Specifies the requirements regarding the performance and the test methods of natural stone setts for external paving (typical road pavements, outdoor squares and outdoor areas, etc.) and road finishes (traffic areas), the assessment of conformity and their marking, and characteristics that are important for the trade.
	EN 1343: Kerbs of natural stone for external paving – requirements and test methods	Specifies the requirements regarding the performance and the test methods of natural stone kerbs for external paving (typical road pavements, outdoor squares and outdoor areas, etc.) and road finishes (traffic areas), the assessment of conformity and their marking, and characteristics that are important for the trade.
	EN 12057: Natural stone products – Modular tiles – Requirements	Specifies the requirements for flat natural stone tiles intended for internal and external use

Table 8: European norms related to natural stone products specifications.

Different types of manufacturing the stone elements for specific reasons

4.1 Processing stone blocks and specific characteristics

The specific kind of natural stone must always be taken into consideration, because it determines the processing cycle, the choice of machinery, the technology employed, the processing cost and the commercial value of the products[53].

Its important to combine and harmonized traditional and modern techniques of manual stone manufacturing, to guarantee unique, excellent and exclusive results both from a technical and from an aesthetic artistic point of view respecting the handcrafted methods. The traditional manual techniques in the different phases of the manufacturing: to draw, to cut, to shape, to carve, to perfect and to enhance the details in the prestigious works, in the reproductions and in the restoration of ancient works. The actual condition of the stone blocks is another issue that influences the choice of the process.

Fractures ("chinks") can be visible or hidden inside the bulk ("vents"). When the material is heavily fractured, stones having great aesthetical features it is difficult to manufacture into finished marketable products (with acceptable yield). The process line may include means to overcome this limitation, that is, equipment designed to repair/consolidate the material.

Cavities, micro- and macro- pores, empties can be also present in a stone. The process line may include means to overcome this limitation, that is, equipment designed to repair/consolidate the material.

Chemical alterations, such as oxidation of inclusions, may result in a decay of the product value, at any stage: during stocking of the raw material, during processing, during stocking of the finished product and also after cladding or flooring.

Geometry (flatness, roughness, irregular shape). According to the desired final product, the manufacturing process should include means to regularize the material geometry, such as lone-standing machines (block-squaring blade cutter or wire cutter), or special operations (such as the block topping operation performed by a multi-disc block cutter).

4.2 Processing technique of stone and machines

The semi-finished or finished products that can be obtained during or at the end of the processing operations can be summarized in the Table 1, classified according to their size.

Product	Length (mm)	Width (mm)	Thickness (mm)
Slab	2500 - 3500	1300 -2000	20 - 80
Thin slab	2500 - 3500	1300 -2000	11 - 20
Not squared slab	As above, edges not trimmed		
Squared slab	As above, edges trimmed		
Strip	1000 - 3500	150 - 650	10-50
Tile (modular tiles)	150 - 650	150 - 650	10 - 12
Super thin (modular tiles)	150 - 650	150 - 650	< 10
Skirting	1000 - 3500	50 - 200	8 - 15
Solid small block	>> thickness >> width	= thickness	= width
Dimensional stone	any	any	> 80

Table 10: Typical products of the processing phase(Gandolfi, et. Al., 2002)

Slabs can be final products (for flooring and cladding); in such cases they are generally squared. Slabs are also semi finished products (generally not squared), to be used for manufacturing dimensional stone products (e.g. kitchen tops) in a "stone laboratory workshop". Slabs are manufactured from the raw blocks in mass production by Diamond cutting Frames, Gangsaws, Wire cutting machines, Giant Disc cutting machines[54]. Before their delivery to a laboratory, slabs can be polished by means of polishing machines.

Strips are semi finished products. In the standard processing plants for mass production. Strips are manufactured by Multi Disc Block Cutters from the raw blocks.

Skirtings can be considered as the finished counterpart of strips. Their finishing requiresmachines designed for this purpose, such as edge polisher and chamfering machines. Generally the standard modular tile processing line is not suitable.

Tiles are final products (for flooring and cladding). Modular tiles come in standard sizes. Tiles can be manufactured from strips using of mass production processing lines.

Solid small blocks are (generally) semi finished product for laboratory finishing. They are manufactured by Diamond cutting Frames, Gangsaws, Wire cutting machines, Giant Disc cutting machines, or even Multi Disc Block Cutters, according to their size.

Dimensional stones are finished products, typically manufactured from slabs or small blocks in small batches, according to a predefined design, in a "laboratory workshop", or in the "laboratory department" of a bigger production plant[55]. Typical dimensional products are: kitchen tops, bathroom tops, furniture elements, architectural elements, tombstones. A wide range of machines is available for laboratories, in order to virtually obtain any possible shape: bridge milling machines, contouring machines, polishers, edge polishers, lathes, water-jet cutter, engraving machines and wire profiling machines.

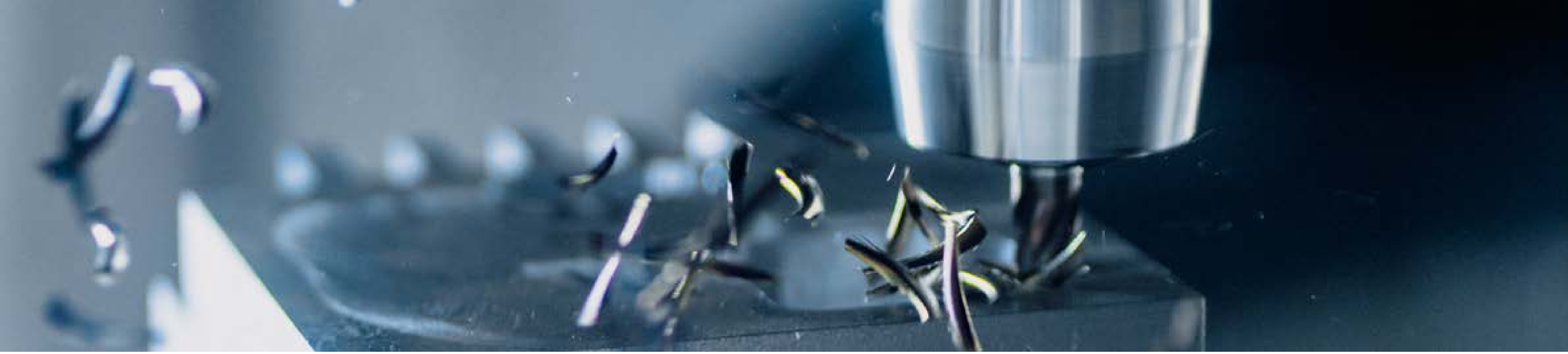
Processing plants, when studied according to their lay out, can be divided in functional areas. Such areas are, in general, also located in different places in the plant. Not all the plants include all the areas, and some plants may include more than one of each area. Small companies, including only the Stone Laboratory, are quite common. On the other hand, plants are always customized, and they can become quite complex because of the combination of many production requirements.

Cutting center: This is the first step, where stone blocks are transformed in to semi finished products. The typically machines installed in this area are Gangsaws[56,57], Diamond Blade Frames[58], Multi Discs Block Cutters[59], Giant Disc Cutters[60], Diamond wire Cutters.

Finishing lines for tiles (modular tiles): Here the semi finished products (strips) are transformed in to finished product (tiles) by means of one or more mass production lines. A wide range of machines are installed here: Calibrating, Polishing, Cross-cutting, Chamfering, Cleaning m/c, Drying m/c, packaging (manual station or automatic packaging center). Filling (Plastering) units with drying ovens are also included, when the processed material requires filling with resins to be repaired.

Finishing lines for slabs: The semi-finished products (slab) are transformed into finished product, by means of one or more mass production lines. Unlike a modular tile plant, here the machines to be installed are quite more restricted in typology: usually, a Slab Polishing Machine, a Slab Cross Cutting Machine, a Slab Trimming Machine (lengthwise cut). Ancillaries for handling the slabs are usually also installed (Slab Loaders and Unloaders, Cranes).

Stone laboratory: The semi-finished products are transformed in to finished products by machines operating in small batches or manually. A wide range of machines is available. These machines may require skilled manpower compared to a mass production finishing line or a cutting center. This manufacturing process is sometimes more related to artwork than to mass production. The productivity of the machines employed can vary among a wide range of values: from the low capacity of a manual machine up to a fully automated CN bridge milling machine[61] or robotic machines[62].
As regards processing cycles, it is possible to design many alternative production cycles depending on the type of raw material and final products. It must be also taken into consideration that a production cycle can be (and often it is) tailored to fit special pro-



cessing conditions, specifications of the final products, raw material features or limitations. This may result either in adjustment of any of the most common processing cycles or in the design of a new system from scratch.

Each one of the basic processing cycles has actually two versions: one for granite ("hard stones", as defined previously) and one for marble ("soft stones"). In some cases, the granite and marble plants require different kinds of machines to perform the same operation. In most cases, the same machine has two counterparts, one for granite and one for marble, which are often very different from many points of view: mechanical structure, tools and machining heads, process control. Even the underlying technology can be different.

The basic processing cycles are the following[63]:

-Cycle for slabs (finished products for flooring and cladding)

-Cycle for slabs (semi finished products for delivery to the Stone Laboratory)

-Cycle for tiles[64], from slabs

-Cycle for mass production of modular tiles (finished products for flooring and cladding)

-Manufacturing of dimensional stones (finished products, Stone Laboratory).

However stone blocks will carefully and ethically sourced. Stone is a material with an extensive number of uses. Always heavy, always long-lasting - it can be rough, smooth, precise, complex, dry, brittle and is be found in an array of complex natural patterns and colours. When carved by hand there is an incredible amount of strength, patience and craftsmanship involved. In a more industrial context, the machines are simply mesmerizing to watch[65].

The industrial processing will include more steps from preparing and finalizations according the requested element[66].

The today's technology for processing the stone is focused in CNC machines have impressive role when it comes to stone. 2-axis routers, 3-axis lathes, 4-axis wire cutters, 5-axis mills - whatever 3D forms you thought you could CNC in wood or metal, you are also likely to achieve in stone.

Like diamond saws, often the CNC tools in stone have diamonds embedded on them so that they can cut through the material. Typically CNC Machines are used to make stone pillars, stone sculptures and bespoke architectural features[67].

The development of technology and applications during the visits in companies are presented in figure 37.

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Management

Control charts for stone industry

Seven types of process waste

Business model canvas in stone industry

Building energy performance assessment as a function of stone facade properties

In recent years, the Natural Stone sector is developing an innovation strategy for the entire sector, so that major milestones focused on Industry 4.0 technologies can be achieved. The continuous changes in the technology internationally applied to the stone, both in quarrying the stone and during its manufacturing and management process, and the advantages that every new technology bring to the industry contribute to reduce costs in a sector where the material to be transformed is hard and difficult to be processes, as the stone is, but also because of this technology is crucial to meet the quality requirements of the international markets, very strict nowadays with the standards and quality requirements.

This eBook presents tailored teaching material for the development of control charts for quality management in stone industry. It explains basic statistical terms later used in evaluating control lines' values and introduces step-by-step procedure on developing the mean control chart and its use in quality control.

CONTROL CHARTS FOR STONE INDUSTRY

1.1 Data distribution

1.1.1 Normal distribution

The normal or Gaussian distribution is one of the most commonly used continuous distributions in probability statistics and theory. The function describing it expresses the probability that the observed value will be found between the selected real numbers, and it tends to zero when it tends to. The normal distribution is sometimes informally also called the bell curve, due to the characteristic shape of the graph representing this function (although there are other distributions of a similar bell shape, e.g. Cauchy distribution or student t-distribution). It was determined using two important statistical values, namely the mean value and the standard deviation, the function it describes is given by

$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$$

The actual nature of the standard deviation can be wellexplained using the normal distribution. If a value is measured in a production process, such as bag filling weight, bottle filling volume or cutting length, the recorded values will usually be distributed exactly according to the normal distribution around the mean value. The distribution of these values will be determined by the value of the standard deviation, which thus determines the width of the bell curve. Figure 1.1 shows the expectation of the distribution of the measured values within the interval around the mean value:

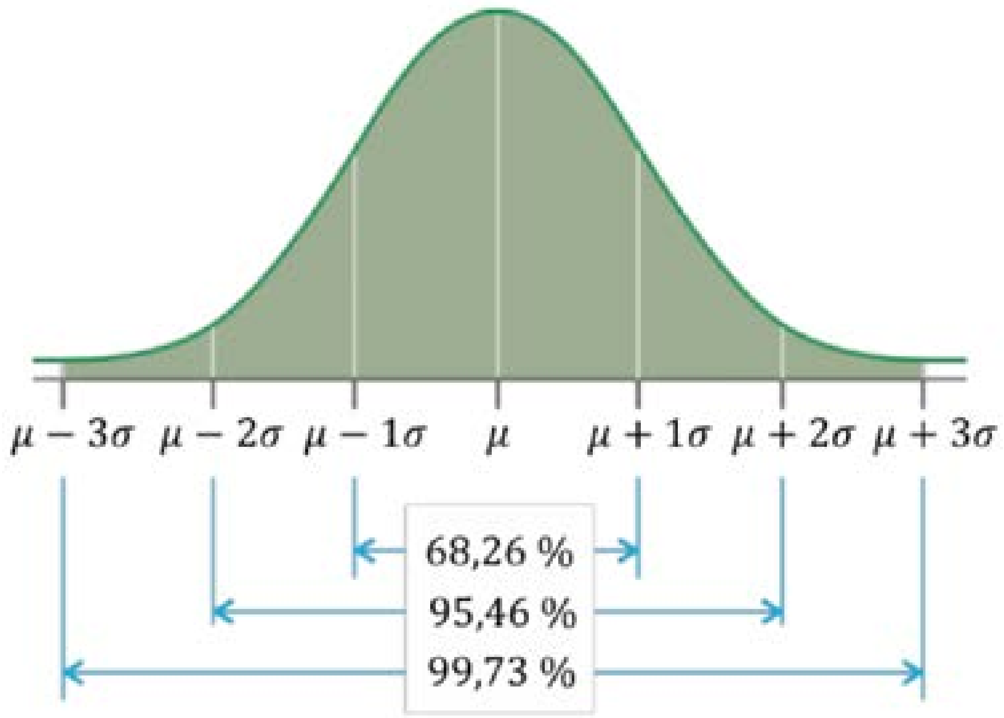


Figure 1.1: Normal Distribution

Although Chebyshev proved the following theorem:

Let μbe the arithmetic mean and let vσbe the standard deviation of the sample x7,x2,...,x:, than in the interval (μ−2σ,μ+2σ)there is at least 75% of data,

and in the interval (μ−3σ,μ+3σ)there is at least 88% of data;however, the empirical rule for bell-shaped distributions is used in practice. The surface is concentrated around thearithmetic mean and is symmetrically distributed to the left and right of it, according to the values shown in

Table 1. The values shown in the table make it possible to estimate for any value that is assumed to be a normal distribution the probability of being within a range of a certain width around the mean valueμ. In the marked fields it can be seen that only around 10% of measurements are expectedaround values greater than μ+1,28σ(or less thanμ−1,28σ), or 2.5%greater than μ+1,96σ(or less thanμ−1,96σ) are expected.

$z = (x-\mu)/\sigma$	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4440	0.4364	0.4325	0.4286	0.4247
...	...	...	...	...	...	...	...	...	...	...
1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
...	...	...	...	...	...	...	...	...	...	...
1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
2.0	0.0228	0.0222	0.0216	0.0211	0.0206	0.0201	0.0197	0.0192	0.0187	0.0183
...	...	...	...	...	...	...	...	...	...	...

Table 1.1: Expectations in normal distribution

1.1.2. Sampling and precision measures

A large number of process adjustments itself can lead to its instability and getting out of control, primarily due to increased variability and therefore the inability to meet process requirements. Proper sampling can help avoid such process manager behavior. For example, it can be expected that the measured specimen will occasionally show a value located at one end of the normal distribution, which could lead to the conclusion that the process needs to be further adjusted. But if a sample of 3, 4, 5 or more specimens is taken, it is very unlikely that all specimens will have values found at one end of the normal distribution. It follows that if individual measurements were to be replaced by the mean value of the sample (constant sizes of 3, 4, 5 or more specimens), then a better insight into the actual state of control or instability of the process would be obtained. Of course, the mean values of a series of samples will be different and show variations, but these variations will certainly be less than when observing individual values, so the samples in some way

"dampen" such variations. Figure 2 shows the distribution of individual values and the distribution of mean values of the samples.

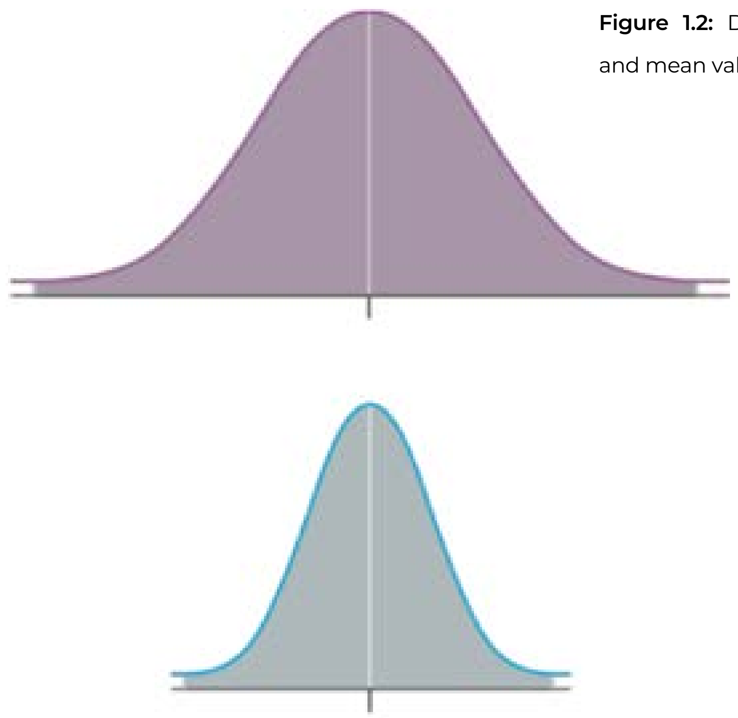


Figure 1.2: Distribution of individual and mean values of samples

In general, the standard deviation of the mean values of a series of samples or the Standard Error SE, is less than the standard deviation of individual values and it is assumed that the following relationship is valid between them:

$$SE = \frac{\sigma}{\sqrt{n}}$$

where n is the sample size, i.e. the number of specimens in each sample (for example, for samples of size 4 specimens, the standard error of the mean values is halved than the standard deviation of the individual values of the entire observed population). Thestandard error of the samples also has the same characteristics as the standard deviation (hence the values from Table 1 are applied to it) and it bears this name mainly to distinguish it from the standard deviation of the population.

Thanks to the narrower mean distribution bell, it is easier to identify (unwanted) changes in the mean of the process, since in this way the cross section of the graphs is much narrower and therefore the shift is more noticeable. This change in the mean value of the processis shown in Figure 3.

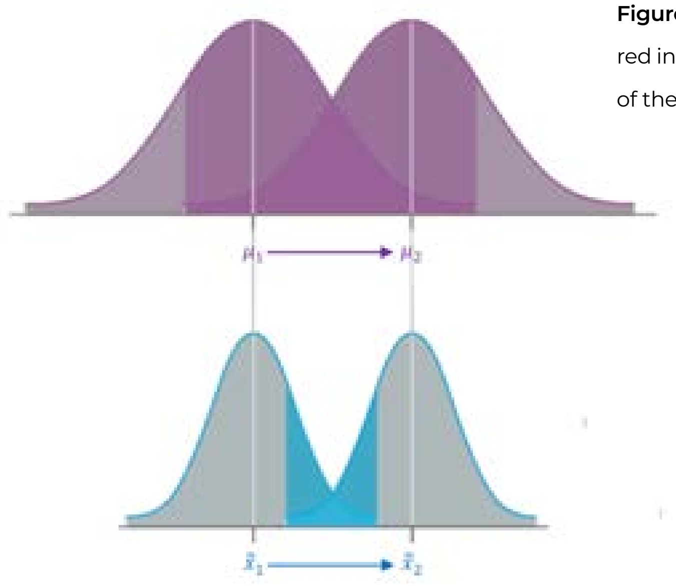


Figure 1.3: Shift the mean of the measured individual specimens and the mean of the samples

values of the samples to control the change in the mean value of the process (centering) than the individual measured values.

1.1.3 Central limit theorem

Obviously, for normal value distribution, above Table 1 is easily applicable to estimate the probability of occurrence, but individual measured values do not always have such a distribution. A very important role for statistical control of the process therefore has the so-called Central Limit Theorem, which states that even if individual values do not have a normal distribution, that the meanvalues of their samples size n, with increasing number n, are increasingly distributed according to the normal distribution, with the same mean $\mu$and standard error of mean values $SE=\sigma/\sqrt{n}$.

Thus, even if the individual values are not normally distributed, the distribution of the mean values of the samples will tend towards a normal distribution, in proportion to the size of such a sample. The mean value of the process, obtained as the mean value of the mean values of the samples, will be a satisfactory estimate of the actual mean value of the population.μ

1.1.4. Sampling and grouping of data

The basic questions after deciding to work with sample values instead of individual values are which sample size to choose and how often to sample. The smaller the sample, the less possibilities for internal variation of the sample, while for larger samples the distribution of their mean values becomes narrower and the changes more recognizable. It is logical to choose the sample size so as to minimize variation between measurements in the sample and increase the possibility of detecting variation between samples. It is certainly necessary to group the data so that changes in shifts, machines, etc. can be easily identified, which can affect the shifts inthe mean value of the process itself.

1.1.5 Examples

Example 1:

In most production processes it is necessary to check whether the product is within the set tolerance of the measured value. For example, the factory packs stonein bags of at least 25kg(less weight is not allowed and would be a market violation) and the measured 100bags are found to have a platform for fostering, modernisation and sustainable growth in natural stone industry in Western Balkansstandard deviation 300 gand that the values are normally distributed. How much bags should actually be filled with stone, so that no more than one of the 250bags is not filled enough, ie. that at most one of the 250bags weighs less than 25kg?

Solution:

One of the 250bags lighter than the default weight of 25kgindicates the left end on the normal distribution bell where the expectation is 1/250=0.0040.From the above table withcumulative standard normal distributionvalues, it can be seen that this corresponds to the value$z$=2.65, so the target charge average is equal to

25,000g+(2.65•300g)=25,795g=25.795kg

Example 2:

The stone factory fills the containers of stone declared with 1ton. Actual charge values are distributed by the normal distribution with a standard deviation of 4kg. If the minimum allowed filling of a containeris exactly 1ton, how much should actually be filled so that at most one of the 50 containers is not filled enough?

Solution:

One of the 50 containersthat are not sufficiently filled indicates the left end on the normal distribution bell where the expectation is 1/50 = 0,020.Fromthe above table of cumulative standard normal distribution, the probability 0,020iscorresponding to =2.05, so the target average charge is equal 1000kg+(2.05·4kg)=1008.2kg=1.0082tons

1.2 Control charts

1.2.1 Control chart model

The control chart is a graphical representation of the quality characteristics measured or calculated from the sample, in relation to the number of samples or the time when the sample was taken. There is a center line on the control chart that represents the mean (average) value of the quality characteristic when the process is under control. In addition to the center line,there is also at least an upper action line and a lower action lineat the chart. The lines of action are determined in such a way thatif the process is under control, almost all points (samples) will be located between them. As long as the points are between the lines of action, no action is required. However, when a point in the process is outside the lines of action, it is said that the process is not under control. It is then necessary to conduct an investigation and corrective actions to find and eliminate the causes that brought the process out of control. Between the center line and the action line are the upper warning line and the lower warning line. When a point is found outside the warning lines, but within the limits of action, then the process is said to be still under control, but now it is necessary to pay more attention to the process, because the process has approached thelimit of action.

Let be astatistical measure of the sample be presented, which measures a quality characteristic. If it is further assumed that the measure $x$has a mean value μ.and a standard deviationσ., then the center line, upper and lower action and warning lines, can be represented by the following:

$$
\begin{aligned}
\text{Upper action line } UAL &= \mu_x + L\sigma_x \\
\text{Upper warning line UWL} &= \mu_x + (2/3)\, L\sigma_x \\
\text{Centerl ine (mean)} CL &= \mu_x \\
\text{Lower warning line LWL} &= \mu_x - (2/3)\, L\sigma_x \\
\text{Lower action line LAL} &= \mu_x - L\sigma_x
\end{aligned}
\qquad 9.1
$$

whererepresents the distance of the control lines from the center line, expressed in standard deviations. This general theory of control charts was proposed by Walter A.

Shewhart, so control charts developed on the basis of these principles are often called Shewhart charts. Following Figure shows the design of the Shewhart control chart.

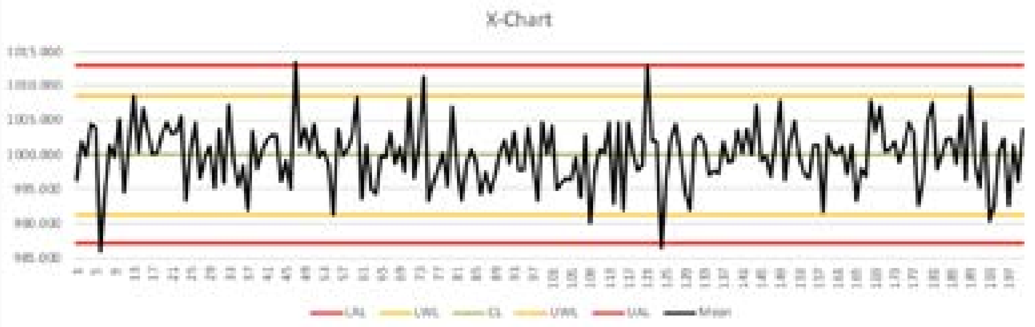


Figure 1.4: Shewart control chart

Control charts explain in a very precise way what is really meant by the term statistical control and as such canbe used in different situations and in different ways. However, control charts are most used in real-time process monitoring. The application of control charts can be easily explained by the following example: sample data are collected on a regular basis,and then a control chart is created based on them. If the sample values are within the control lines and do not show any systematic patterns of sample distribution, then such a process is said to be under control. Control charts are used to draw conclusions about the state of the process in the past, but they can also be used to predict the future state of the observed process.

1.2.2 Analysis of point distribution patterns on control charts

Control charts can indicate a process out of control when one or more points are outside the lines of action, or when the points follow some non-random and unusual pattern of occurrence (distribution). The problem is in recognizing systematic or non-randompatterns of the appearance of points on control charts and determining the reasons for these phenomena. The ability to interpret certain patterns, in terms of determining special causes, requires experience and good knowledge of the process. Not only knowledge of the statistical principles of control charts is enough, but good knowledge and understanding of the processes being controlled is of particular importance. A large number of tests have been developed to determine different types of non-random and unusual occurrence patterns, and someof them are described and graphically presented in the section below. Assuming data normality,each of these patterns has a probability of occurrence of less than 0.005, when the process is under control.

The tests that can be used to determine non-random and unusual distributions of points on control charts are:

·One point outside the line of action`

·Sevenor more consecutive points below or above the center line.

·Six or moreconsecutive points in ascending or descending trend.

Graphical representations of these tests are shown in the below Figure.

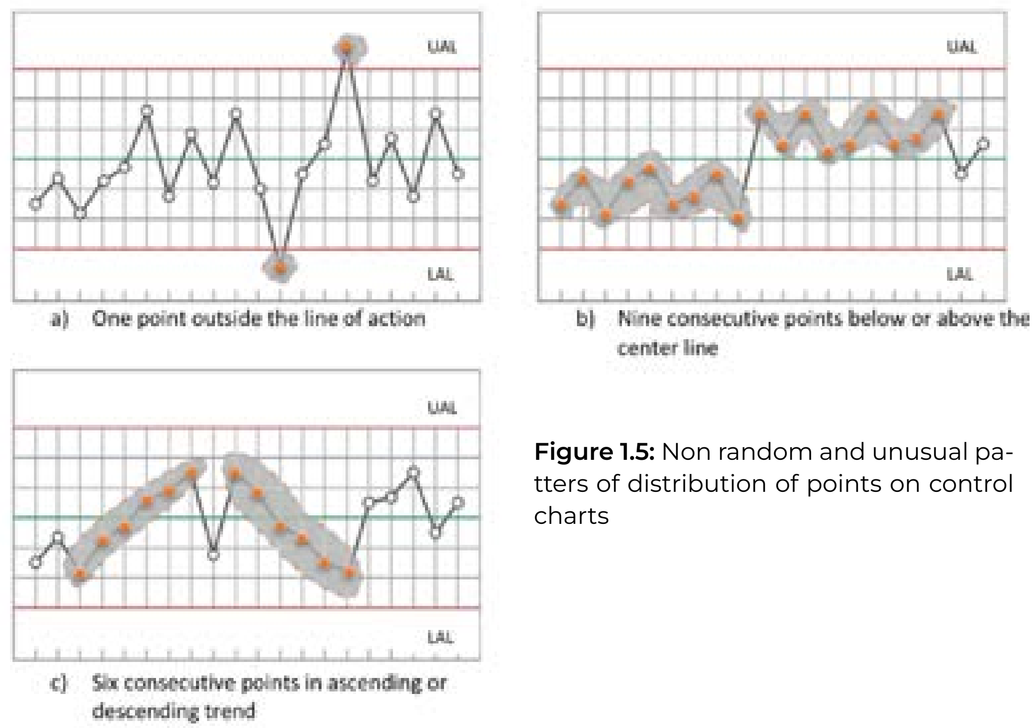


Figure 1.5: Non random and unusual patters of distribution of points on control charts

1.2.3 Control charts for mean values and ranges -$x$nand Rcontrol charts

Many quality characteristics can be expressed by numerical measures. A measurable quality characteristic, such as length, diameter, mass, volume or stress, is called, in the context of statistical quality control, a variable. When a quality characteristic is controlled, which is a variable, its mean value and its variability are usually controlled. The control of the mean value of the process, or the mean value of the quality level, is usually performed by control charts for the mean values, ie □ncontrol charts. Control of process variability, or variability in quality levels, is usually performed either by control charts for standard deviations, also called □control charts, or by control charts for ranges or □control charts. A control chart is more often used to control the variability of quality characteristics. Usually both $R$and$\bar{x}$control chart areused to control quality characteristicsat the same time. $R$and (or) $\bar{x}$control charts are considered one of the most important and useful tools ofstatistical quality and process control.

In reality, the mean $\mu$and standard deviation $\sigma$of the process are not known. Therefore, these values must be determined from preliminary samples taken from the process when the process was considered to be under control. It is usually recommended to take at least 20 to 25 samples.

Let$m$samples were taken from the process, with each sample contains $n$observationsof the desired quality characteristic. Usually the sample size$n$is small and contains from 4 to6 test units. The reason for the small sample size is that it is impractical and expensive to take a large number of control units. Let now $\bar{x}$7,$\bar{x}$2,...,$\bar{x}$vbe the mean values of each of the □samples taken from the process. The estimate of the mean value □of the process can be determined using the mean value $\bar{\bar{x}}$of all samples, using the following form:

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \cdots + \bar{x}_m}{m}$$

The mean $\bar{\bar{x}}$of all sample mean values, as the best estimate of the process mean μ, will be the center line $\bar{x}$of the control chart.In order to determine the control lines, it is necessary to estimate the standard deviation of the process. For the case under consideration, it is shown below how the standard deviation □of the process is estimated using a range.

Let the observations $x_1, x_2, \ldots, x_n$ be the quality characteristics in the sample size. The range of any sample is then the difference between the largest x_{max} and the smallest observation x_{min}, i.e. $R = x_{max} - x_{min}$. Let $R_1, R_2, \ldots, R_m$ be the ranges of all the m samples. The mean range of all samples taken from the process is $\bar{R}$

$$\bar{R} = \frac{R_1 + R_2 + \cdots + R_m}{m}$$

The center line $\bar{\bar{x}}$, upper and lower action and warning lines, for the control chart, can be determined using the forms given below:

$$\begin{aligned} \text{UAL} &= \bar{\bar{x}} + A_2\bar{R} \\ \text{UWL} &= \bar{\bar{x}} + (2/3)A_2\bar{R} \\ CL &= \bar{\bar{x}} \\ \text{LWL} &= \bar{\bar{x}} - (2/3)A_2\bar{R} \\ \text{LAL} &= \bar{\bar{x}} - A_2\bar{R} \end{aligned}$$

The values of constant A_2 and, for different sample sizes n, are given in the table in Annex. The center line, upper and lower action and warning lines, for the R control chart, can be determined using the forms given below:

$$\begin{aligned} \text{UAL} &= D'_{0,001}\bar{R} \\ \text{UWL} &= D'_{0,025}\bar{R} \\ \text{CL} &= \bar{R} \\ \text{LWL} &= D'_{0,975}\bar{R} \\ \text{LAL} &= D'_{0,999}\bar{R} \end{aligned}$$

The values of the constants $D'_{0,001}$, $D'_{0,025}$, $D'_{0,975}$, $D'_{0,999}$, for the different sample sizes n, are given in the table in Annex.

The stonefactory packs stones. The factory quality control department wants to establish statistical control of the stoneproduction and packaging process using $\bar{x}$ and control charts. Every hour, 5 packs of stonesare taken from the process and the weight of the packs is checked. The data in Table 9.1 were measured on 24 samples, each 5 units in size, at times when production was considered to be under control.

sample	m1	m2	m3	m4	m5
1	198.28	194.66	202.78	193.75	199.14
2	194.66	202.78	193.75	199.14	200.68
3	202.78	193.75	199.14	200.68	205.30
4	193.75	199.14	200.68	205.30	201.34
5	199.14	200.68	205.30	201.34	198.13
6	200.68	205.30	201.34	198.13	205.07
7	205.30	201.34	198.13	205.07	193.54
8	201.34	198.13	205.07	193.54	206.94
9	202.40	196.86	197.42	200.46	198.30
10	196.86	198.80	200.46	195.54	199.67
11	191.42	200.46	195.54	199.67	203.63
12	200.46	195.54	199.67	203.63	197.52

sample	m1	m2	m3	m4	m5
13	195.54	199.67	203.63	197.52	196.78
14	199.67	203.63	197.52	196.78	201.23
15	203.63	197.52	196.78	201.23	198.93
16	197.52	196.78	201.23	203.94	192.57
17	210.85	197.03	197.93	200.02	207.37
18	197.03	197.93	200.02	207.37	205.33
19	197.93	200.02	203.20	205.33	207.37
20	200.02	204.20	205.33	203.50	203.70
21	202.80	205.33	198.60	204.80	200.64
22	205.33	207.37	206.78	200.64	198.27
23	207.37	206.78	200.64	198.27	199.60
24	206.78	200.64	198.27	203.65	197.37

Table 1.2 Stone pack weight

When $\bar{x}$and Rcontrol charts are used to control the process, it is recommended that a □control chart be created first. In the first phase preliminary data are used to determine whether the process was under control when the data were collected. For the 24 samples collected, the ranges R_i of each sample are given in Table 1.3.

Table 1.3 Sample ranges

Sample	Range R_i	Sample	Range R_i
1	9.03	13	8.09
2	9.03	14	6.85
3	11.55	15	6.85
4	11.55	16	11.37
5	7.17	17	13.82
6	7.17	18	10.34
7	11.76	19	9.44
10	4.92	22	9.1
11	12.21	23	9.1
12	8.09	24	9.41

The mean $\bar{R}$of all ranges is the center line of the Rcontrol chart, and is determined with:

$$\bar{R} = \frac{\sum_{i=1}^{24} R_i}{24} = \frac{217.83}{24} = 9.08$$

For size samples$n$=5, from the table in Annex following values D(.)~for constants are used:

Sample size n	$D'_{0,999}$	$D'_{0,001}$	$D'_{0,975}$	$D'_{0,025}$
4	0.10	2.57	0.29	1.93
5	0.16	2.34	0.37	1.81
6	0.21	2.21	0.42	1.72

Control lines are determined as:

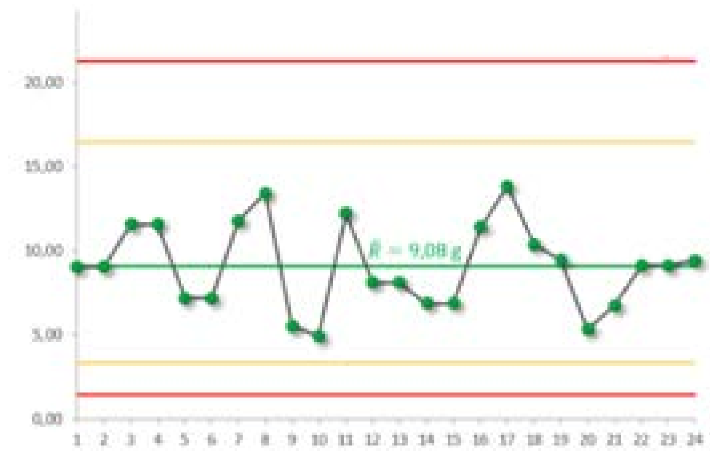
UAL $= 2.34 \cdot 9.08 = 21.24$

UWL $= 1.81 \cdot 9.08 = 16.43$

CL $= 9.08$

LWL $= 0.37 \cdot 9.08 = 3.36$

LAL $= 0.21 \cdot 9.08 = 1.45$



Rcontrol chart, with the center line and the upper and lower action and warninglines, is presentedwiththe above Figure 3. The ranges of each preliminary sample are plottedon the chart. It can be seen that there are no points outside the action lines or warning lines, so it can be concluded that the process is under control.As process variability is under control, .$\bar{x}$control chart can now be approached. For the 24 collected samples, the mean values $\bar{x}_i$ of each sample are given within the Table 1.4

Sample	Mean value $\bar{x}_i$	Sample	Mean value $\bar{x}_i$
1	197.72	13	198.63
2	198.20	14	199.77
3	200.33	15	199.62
4	200.04	16	198.41
5	200.92	17	202.64
6	202.10	18	201.54
7	200.68	19	202.77
8	201.00	20	203.35
9	199.09	21	202.43

Table 1.4 Mean valyes of the samples from examples 1

The mean $\bar{\bar{x}}$of allsamples'means $\bar{x}z$is also the center line of the control chart, and is determined using Form 9.2:

$$\bar{\bar{x}} = \frac{\sum_{i=1}^{24} \bar{x}_i}{24} = \frac{4{,}812.56}{24} = 200.52$$

For sample size n=5, from the table in Annex, values for constants A2and 23⁄A2are

Sample size n	A_2	$2/3\,A_2$
4	0.73	0.49
5	0.58	0.39
6	0.48	0.32

$\bar{x}$control chart with the center line, and the upper and lower action and warning lines is presented with Figure 1.4:

$$\begin{aligned}
\text{UAL} &= 200.52 + 0.58 \cdot 9.08 = 205.79 \\
\text{UWL} &= 200.52 + 0.39 \cdot 9.08 = 204.06 \\
\text{CL} &= 200.52 \\
\text{LWL} &= 200.52 - 0.39 \cdot 9.08 = 196.98 \\
LAL &= 200.52 - 0.58 \cdot 9.08 = 195.26
\end{aligned}$$

¯control chart with the center line, and the upper and lower action and warning lines is presented with Figure 1.6:

Figure 1.6: n packing weight control chart

The mean values of all preliminary samples are plotted on the chart. Looking at the $\bar{x}$ control chart, it can be seen that there are no points that cross the lines of action. Since the $\bar{x}$ and R control charts do not have points outside the lines of action, it can be concluded that the process of production and packaging of stoneis under statistical control, and preliminary control lines can be adopted and used for future control of the observed process.

1.3 Process capability analysis

How effective an organization is in meeting the needs and desires of customers is measured by the ability of its processes to produce products and / or services that meetsor exceedscustomer requirements. Customer requirements are significant features that a customer expects to find in a product or service. Design engineers translate these customer requirements into the quality characteristics of the product or service they intend to produce. Quality characteristics are fully embedded in product design, as product variables or attributes, and they are used as measures to ensure that production processes meet customer requirements. Once the product quality characteristics have been determined and the quality objectives have been set, engineers specify the upper and lower limits within which the specified variables must be located -quality characteristics.

While production is in progress, process performance is constantly monitored. A tool often used to monitor and track performance while production is still in progress are control charts. Control charts help identify specific causes of variation and define preventive and corrective actions. However, checklists are not the right tool to determine customer satisfaction, as they are only used to monitor the performance of the production process in progress, and the controlled process does not necessarily mean that all products produced meet customer requirements. In other words, the process can be contained within the upper and lower control limits (action line), but still produces products that are outside the specification limits. To avoid ambiguity, it is common for specification limits to relate to customer requirements, that is, the requirements of the designer of the product / service, while the control limits refer to the process of production / provision of the service. Control charts do not establish a relationship between process performance and customer requirements, as there is no statistical or mathematical relationship between engineering-specified limits and process controllimits. Process capability analysis is a bridge between process and customer requirements. It compares the variability of a production process, which is stable and under control, with its engineering specifications, and it determines process capability indices to measure the level of process performance that meets customer requirements. because there is no statistical or mathematical relationship between engineering-specified limits and process control limits. Process capability analysis is a bridge between process and customer requirements. It compares the variability of a production process, which is stable and under control, with its engineering specifications, and it determines process capability indices to measure the level of process performance that meets customer requirements.

Process capability analysis (Montgomery, 2009) is a vital part of a comprehensive quality improvement program.

Among the most important benefits of process capability analysis are the following:

·It helps to predict the ability of the process to maintain tolerances (boundaries).

·Assists product development / design engineers in selecting or modifying processes.

·Helps establish sampling intervals.

·Helps determine the requirements for the purchase of new equipment (machines).

·Assists in supplier selection and other aspects of supply chain management.

·It helps in planning production processes when there is an interactive impact of processes on tolerances.

·Helps reduce process variability.

Thus, process capability analysis is a technique that has application in many segments of product lifecycle, including product and process design, supply chain management, production planning, and production in general.

A process is said to be capable if the mean process value is centeredtoward the target value and if the range of specification limits is wider than the actual process variations, as in Figure 1.7. The specification limits on the left side of the image represent the customer's requirements, while the control chart, on the right side of the image, represents the process performance. In this example, all products are considered to be compliant and manufactured in accordance with the specifications, sincethe distribution width of the process samples (on the left) is lowerthan the specification limits.

If the scattering of natural variations (control limits) is greater than the specification limits, as shown in Figure 1.8, then the process is said to be incapable. In this example, it can be seen that the distribution width of the process samples

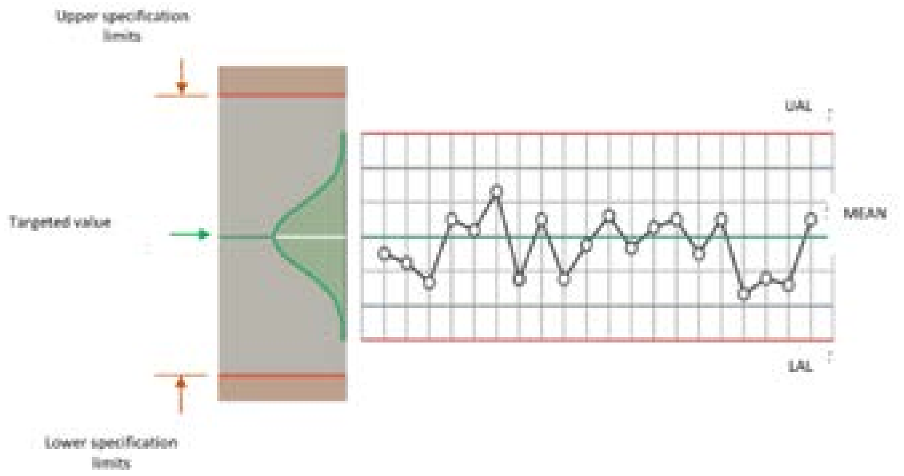


Figure 1.7: Example of a capable process

is wider than the specification limits, so the products in the distribution tails (marked in red) can be considered non-compliant, ie. products that do not meet the set specifications. Sometimes non-compliant product units can be reprocessed and become compliant. For example, if in Figure 6 the quality characteristic was the weight of a unit, then units whose diameter is larger than the upper limit of the specification, by additional processing might be adjusted to meet the set specifications, ie. these units could become aligned. But units with lower weightthan the lower limit of the specification cannot be further processed, so they are considered to be definitely non-compliant units (scrap).

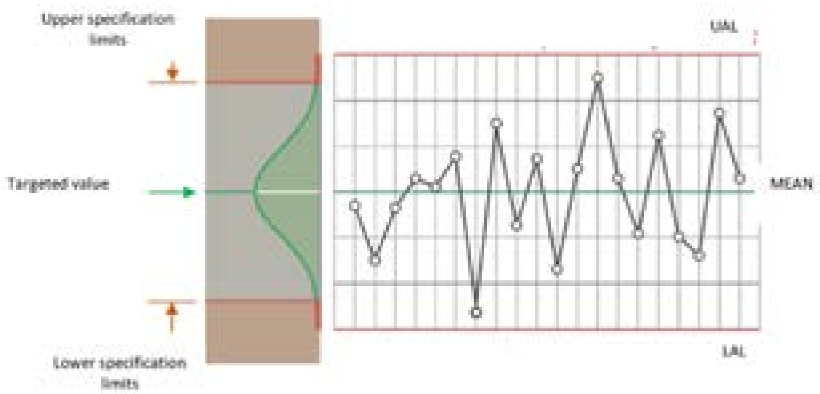


Figure 1.8: Example of a process that is not capable

1.3.1 Process capability indices

Cpindex measures the ability of a process to meet set specifications. The estimated standard process deviation$R\{d2/$is used to calculate this index when control charts $\bar{x}$and□are used for process control (d2values are given in the table in Annex). According to the above, the .C index represents the potential of the process to meet the set specifications. This index does not take into account the position of the mean value of the process, but the scattering. If the process is not centered against the set specifications, the C index itself may give incorrect information.

The higher the value of the index C the less scatter the process output. A low-scatter process does not mean that the process meets the set specifications at the same time if the mean value is not centered onthe target value. If, on the other hand, the mean value of the process is centered with the target value, then the C index should be used together with the index C , in order to take into account the mean value and the scatter of the process. The indices C and$C$ will be equal in value only when the mean value of the process is centered according to the target value.

The value of the C index is calculated with:

$$C_p = \frac{USL - LSL}{UAL - LAL} = \frac{USL - LSL}{6\hat{\sigma}}$$

Where USL is upper specification limit, LSL is lower specification limit, UAL is upper action line, LAL is lower action line and $\sigma = \bar{s}$or$\sigma = R\{d2/$is estimate of standard process deviation.

Cpkindexmeasures how well the process actually meets the set specifications. An estimate σ of the standard deviation of the process is also used to calculate the index C , and therefore shows the potential of the process to meet the specifications. As the position of the process mean $\bar{\bar{x}}$ is also used to calculate the index$C$, the process does not have to be centered in relation to the target value in order for this index to be used.

The value of the C index is calculated based on the form:

$$C_{pk} = \min\left(C_{pku}; C_{pkl}\right)$$

$$C_{pku} = \frac{USL - \bar{\bar{x}}}{3\hat{\sigma}}; \; C_{pkl} = \frac{\bar{\bar{x}} - LSL}{3\hat{\sigma}}$$

From the above equiationit can be seen that to calculate the index C it is necessary to first calculate the two values C and C, and then adopt the smaller one. If both values are equal, then the process is centered accor-ding to the target value. If the values are different, then the mean value is shifted to a lower one. For example, if the index C is smaller, then the mean value is shifted towards the upper limit of the specification; and if the index C is smaller, then the mean value is shifted towards the lower limit of the specification.Some characteristic values of the C index and their meaningare as follows:
The range of specifications is equal to the range of natural process variations (control chart range). This process is said to be barely capable. Such a process is only able to produce products without non-conformities (defects), if themean value of the process is centered according to the target value. Approximately 0.27% or 2,700 units of products per million are non-compliant.

The range of specifications is greater than the range of natural process variations. The process is potentially capable if the mean value of the process is centered toward the target value. This process “proba-bly” produces products that meet or exceed customer requirements.

The range of specifications is smaller than the range of na-tural process variations. The process is incompetent and produces non-compliant parts.
Within each company there are various types and forms of losses.

SEVEN TYPES OF PROCESS WASTE

In Lean production philosophy the waste is any activity in processes that does not add value from a customer perspective. In other words, waste is any activity (step, process) that the customer is not willing to pay for.

The systematization of seven types of waste (jap. Muda) was developed by Taiichi Ohno. Taiichi Ohno was the chief engineer at Toyota and one of the most deserving people for the development of the Toyota Produc-tion System (TPS) or Lean Production System. The seven Lean losses ac-cording to Ohno are (acronym TIMWOOD): **Transport Inventory, Move-ment, Waiting, Overproduction, Overprocessing (extra-processing), Defects.**

Figure 2.1: Seven types of lean waste

Transport Waste

Definition:

Any type of transport of materials, parts and information, products and people between processing centers, factories and warehouses.

Causes of loss:

Bad layout, large Inventory, overproduction, poorly designed process, a complex material flows, very long distance between processes or objects. silo organization, poor supply chain management (SCM).

Consequences, problems, costs:

Increased transport and search costs.

Longer delivery time.

Increased damage.

Inventory waste

Definition:

Raw material of any kind, Work in Progress (WIP) or finished products stored.

Causes of loss:

Oversupply. Overproduction. Poor planning. Poor organization. High setup costs. Poor SCM.

Consequences, problems, costs:

Inventories are expensive

They require space

They cover up problems in the process

Could be damaged

Motion waste

Definition:

Every unnecessary movement made by an employee in work: searching, bending, stacking, etc.

Causes of loss: Bad layout. Poorly designed process, Bad housekeeping Non-standardized operating procedures. Overproduction.

Consequences, problems, costs:

Increased cycle time

Increased costs.

Decreased safety

Waiting waste

Definition:

People or parts are waiting for the work cycle to be completed.

Waiting for the machine to finish processing, waiting for materials, waiting for information, waiting for spare parts, etc.

Causes of loss: Unreliable supply chain Bottlenecks, the process is not balanced High setup costs. Machines and man aren't flexible. Poor planning and organization. Failures.

Consequences, problems, costs:

Increased cycle time

Increased costs.

Causes bottlenecks.

Overproduction waste

Definition:

Produce more than ordered or produced before the delivery time.

Causes of loss: Poor planning, Bad assumptions about bottlenecks, Unreliable processes, suppliers.

Consequences, problems, costs:

Leads to most other losses

Low throughput.

Overprocessing waste

Definition:

Actives that generate a higher value than the customer requests.

Inadequate methods and procedures that generate higher costs than adequatic methods and procedures.

Causes of loss: Poor customer focus, “Always works like this.” Lack of understanding of the buyer’s needs, Lack of standardization and regulations, processing time according to the forward plan greater than required.

Consequences, problems, costs:

Increased cycle time

Increased costs.

Defects

Definition:

When customer (internal or external) did not get what he paid for.

Errors, scrap, scrap material.

Causes of loss: Customer requests are not understood, mismanagement of processes, focus on control, not processes, obsolete equipment, poor motivation, lack of standardized work, unclear or complex processes .

Consequences, problems, costs:

Increased cycle time

Increased costs.

Losing customer trust.

SEVEN WASTES OVERVIEW - RESEARCH ARTICLES, THESIS, REPORTS

https://leanmanufacturingtools.org/77/the-seven-wastes-7-mudas/

https://www.planettogether.com/blog/seven-types-of-waste-in-lean-manufacturing

https://www.youtube.com/watch?v=GaBdscrrXL8

https://www.youtube.com/watch?v=VWN8NrJ7LE8

https://www.youtube.com/watch?v=SU01D-jTZcE

SEVEN WASTE REGOCNITION AND ELIMINATION

https://www.youtube.com/watch?v=PpNmsQm_YSw

https://www.youtube.com/watch?v=jPp_3-zfPaQ

SEVEN WASTE ELIMIANTION - EXERCISE (YOUTUBE VIDEO + EXECISE)

https://www.youtube.com/watch?v=T5bEGoQAByU

https://www.youtube.com/watch?v=bh7L0YuuW5s

LEAN PRINCIPLE IN STEONE AND MINING INDUSTRIES - RESEARCH ARTICLES, THESIS, REPORTS

Implementing Lean Principle into Mining Industry Issues and Challenges

Abstract:

The lean production concept has its origin in automotive industry and is widely used in manufacturing sectors. What makes its applicability in mining difficult is the dynamic nature of mining operations bringing high degree of uncertainty in various unit operations. To reduce the wastage of efforts, one needs to remove uncertainty and predict the process behaviour as correct as possible. Furthermore, to achieve lean approach in mining, the entire mining chain needs to be considered starting from Mine exploration, mine planning, drilling operation, blasting, loading and transportation, ore dressing processes, reclamation, etc. To be lean in mining is not only dependent on mine production systems consisting of equipments and machines but it also depends on quality and reliability of information flow in real time generating action plans. Also, the reliability and maintenance preparedness have major influence on the degree of waste being generated in the process. For example if ore body is not correctly delineated/characterised or drilling operations not performed correctly, wrong charging process and wrong loading process- all may lead to wastage of resources. In fact Lean production has its origin (leans on) in JIT, TQM and TPM. The common denominator of all these philosophies is the human in the process. To improve any process one needs to measure the current status so that any change in current status can be recorded. The paper presents issues and challenges associated with implementation of Lean Principles in Mining industries.

Available:

https://www.iqpc.com/media/1000518/31354.pdf

A Lean Implementation Framework for the Mining Industry

Abstract:

The adoption of Lean concepts beyond the manufacturing sector has been increasing recently. In this line, its scope has been expanded to the mining industry under the realisation of the need for productivity improvements and a leverage for efficient operations. Limited research exists regarding Lean implementation in the mining industry in a comprehensive and structured way. This paper therefore follows a systematic approach to review the current literature to identify Lean implementation patterns in the mining sector, its scope, challenges, and limitations. The results reveal the limited utilisation of Lean and that there is a lack of coherent and conceptual models to guide the implementation of Lean in this industry. Hence, the research proposes a framework for Lean implementation in the mining industry.

Available:

https://www.sciencedirect.com/science/article/pii/2405896318315623

Flexible-lean processes optimization A case study in stone sector

Abstract:

During the downturn in demand in Engineering and Construction Architecture (AEC) activities registered in 2007, the Cluster of Mineral Resources of Portugal (CPMR) put into practice an initiative to boost the Ornamental Stone sector, based on incorporating lean thinking concepts, combined with techniques and technologies to make production processes more flexible. This was called the leanstone hornbook (LH). Since then, the LH has been adopted by several Portuguese Ornamental Stone (OS) companies. For these companies, using the LH means changing their operations to a new model based on (i) their participation in R&D consortium projects, (ii) incorporating the resulting innovations, and (iii) combining innovation with lean thinking. Based on a convenience sample of OS companies, the objective of this research was to assess the economic-financial impact of leanstone operations on Portuguese OS companies. Through a methodological framework based on Key Performance Indicators (KPI) and Innovation Outcomes (IO), indexed to companies' economic-financial performance, LH was found to generate a potentially positive impact in terms of sales volume, exports, investment capacity and net result.

Available:
ciencedirect.com/science/article/pii/S2590123020300359

LEAN TOOLS SELECTION FOR MINING: AN OCCUPATIONAL HEALTH AND SAFETY APPROACH (Master Thesis)

Abstract:

The implementation of lean principles is a well-known subject in the manufacturing industries. There are several publications regarding the impact of this implementation on productivity and workers' occupational health and safety (OHS) in this sector. In mining industries, however, the link between lean integration and OHS is missing and the publications regarding this issue are scarce. In this thesis, an attempt was made to address this issue and investigate more about lean mining in Canada. For that purpose, a literature review followed by an expert elicitation study were conducted. The main objectives of this thesis were to find out about the proper lean tools to be implemented in the mining industry and to investigate about their links with an important productivity indicator (i.e. daily advance rate) and OHS indicators (i.e. body reaction and struck by an object) in the Canadian underground gold mining. Based on the results of this thesis, a lean mining lifecycle framework with four different phases and a set of lean tools (i.e. VSM, 5S, Kaïzen, TPM, SMED and LIC) were proposed for the mining sector. Furthermore, according to the expert elicitation (7 Canadian experts), 5S and TPM could have positive impacts on daily advance rate and kaïzen could potentially enhance the miners' safety by reducing the rate of struck by an object risks at their workplace. A lean mining preliminary road-map was proposed based on these findings. This study's results can be used as a stepping stone in future studies to gain a better understanding about lean mining integrating OHS issues in Canada.

Available:

https://espace.etsmtl.ca/id/eprint/2363/1/NEMATI_ROUZBAHANI_Ali.pdf

Lean Production in Mining (RESEARCH REPORT)

Concluding remarks:

LP is a mind-set based management model and, as such, much of the work in realising LM will have to happen in the minds of employees and the em- ployer. Values and philosophy will have to be aligned to those of LP. This, in itself, might constitute a significant part of the implementation efforts.

Following the realisation of the "soft" part of the concept, the principle of waste elimination seems most suitable for implementation. These practices and tools will have to be adapted and practiced throughout the company, and there is evidence of this being possible and advantageous. Also, integrat- ing suppliers should beneficiary, especially if this solves the issue of contrac- tors (either through integration or substitution). As the practice of supplier integration would differ little from other application areas of LP, it should be ready for implementation to mining. Demand-based production will have to be focused on supporting functions as a start. As work towards actualising continuous mechanical metal miners continues, the principle can start being implemented to the production process as well. And finally, the involvement of the workforce should encompass the entire implementation effort.

All in all, it seems that the mining industry is ready to at least being its jour- ney towards LM. Even though some problems remain to be solved, they should not be considered severe enough to discourage starting LM efforts.

Available:

http://ltu.diva-portal.org/smash/get/diva2:996836/FULLTEXT01.pdf

Business model canvas in stone industry

3.1 Effective and efficient sides of business

3.1.1 Effective side of business

Most frequent reasons why businesses in stone industry fail are that businesses offer product or service for which there is no demand at the market, or sometimes it may happen that businesses in stone industry offer products or services for which there is demand but with the price so high that the customers are not ready to give their money for that product or service.

Without customers any business is doomed to fail. According to the true guru of management theory Peter Drucker, there is only one valid definition of the purpose of business ant that is to create and retain a customer. Without a customer, there is no business. While there are demand and customers for product or service in stone industry, there are supply and businesses. When demand disappears, so do businesses.

The purpose of a business in stone industry is to create a customer in such a way that the customer is offered the “right thing” at all times -a product or service in stone industry that the customer perceives as “value”. If the buyer is not offered the “right thing”, the act of purchase will not happen. If there is no purchase of products or services in stone industry businesses fail. So, customers make the business “alive”.

Therefore, the purpose of the business in stone industry isto “create and retain a customer” on an ongoing basis. Loss of customers also leads to business closure.

Creating and retaining customers on an ongoing basis is only possible if businesses in stone industry are behaving innovative and if at all times, they keep customers and their needs and wants, specific way of meeting needs, in the focus of their actions.

According to Peter Drucker, every business has two -and only these two basic business functions: innovation and marketing, and everything else are “costs”.

Through these two basic functions, innovation and marketing, business in stone industry puts the customer and his/her wants and needs at the center of its ´interest. By improving existing or creating completely new products made from stone or services in stone industry businesses should try to meet customers’ needs and wants in a superior way unencumbered by the way customers themselves see satisfaction of needs and wants as once Henry Ford said: “If I asked people what they wanted, they would say faster horses” or what Steve Jobs said: “It’s not the job of customers to know what they want”.

3.1.2 Efficient side of business

However, for a business to be successful and sustainable, it is not enough to just “create a customer” and offer the “right thing”. Creating a customer is a “conditio sine qua non”. In other words, it is a necessary but not a sufficient condition. Thus, in order for a business to be successful, it is necessary not only to do the “right thing”, but also to do the “right thing” in the “right way”.

The “right way” refers to how to “make” a product or service in stone industry with minimal expenditure of resources, with the highest possible productivity and, ultimately, with the lowest possible cost. Through the “right way”, assumptions are made that the product or service in stone industry is offered at a price that the customer is willing to pay.

The “right way” is oriented inside the business and has the opposite logic from the “right thing”.Designing the “right way” helps innovation of business processes in stone industry through so-called business process innovation for example innovation of the production processeses or technological innovation, with a focus on how to improve the ways of “creating” the product or service in stone industry itself.

3.1.3 Successful businessin stone industry

Being successful in business in stone industry means ensuring the right balance between the “right thing” and the “right way” as two opposing business concepts. Doing right thing means being effective, while doing in a right way means being efficient. Therefore, to be effective means to be completely outside oriented, towards demand, towards customers and towards competition. Businesses in stone industry that are not effective cannot be successful.

Being effective is a basic premise for being successful. Efficiency is opposite concept of business in stone industry and means doing in the right way, with minimal expenditure of engaged resources and the highest possible productivity. Being efficient means being inside oriented, with a focus on maximizing productivity and lowering costs in the process of creating “things” that are offered to customers.

So, effectiveness is a concept completely outside oriented (towards the market, demand, customer and competition), with the aim of shaping the “right thing”, while efficiency is completely inside oriented concept (towards resources, productivity, costs, expenses), with the aim of engaging and using resources in the “right way”.

Successful business in stone industry is reflected in the ability to have these two opposite sides of the business, effectiveness and efficiency, in balance, attempting to achieve both higher efficiency and higher efficiency. Successful businesses in stone industry are both effective and efficient, and this is where the complexity of running a successful business in stone industry is reflected. And it is not at all easy to keep these two opposing concepts in balance.

In order to achieve this balance good business model should be created. Here, business model canvas as a tool to create model for the business in stone industry is briefly presented.

3.2 From business idea to business to business model

3.2.1 Business model canvas

Business model canvas is a tool used to develop new business models as well as to document and improve existing business model and it was proposed by Alexander Osterwalder.

Business model canvas consists of nine building blocks as follow: **Value proposition, customer segments, customer relationship, channels, revenue streamsKey activities, key resources, key partners, costs structure.**

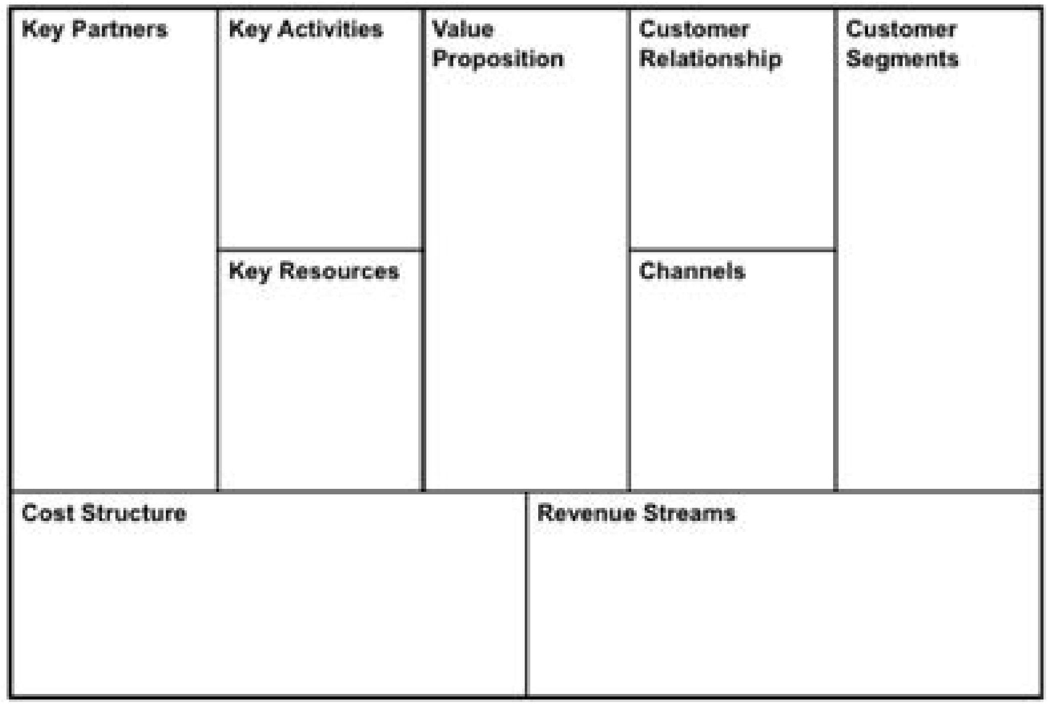


Figure 3.1: Business model canvas

3.2.2 Developmentof business model canvas

Value proposition canvas is usually the first step in building business model canvas. The real challenge is to convert business idea into value proposition which we want to deliver to customers and which customers want. For a business in stone industry, it should be clear who are the customers who need products or services in stone industry. With full empathy, businesses in stone industry should understand and identify customer´s needs and wants. Also, negative outcomes

and obstacles while doing activities customers want to avoid and which make them "pain" should be understood and identified, as well as positive outcomes and successfully completed activities which customers wants to achieve and which make customers "happy" should be understood and identified. So "gains", what makes a customer happy, and "pains", what makes customer sad, should be clearly identified including customer´s activities. That in short how customer profile could easily be built.Value map is something that should be created based on the product or service in stone industry that value proposition is built on.

Since a customer wants to achieve gains and avoid pains value proposition should give answer on two basic questions:

–How product or service in stone industry create, "gains" for customer.

–How product or service in stone industry relieve or eliminate "pains" of customer.

In other words, value proposition could be understood as medicine for customer´s pains so as to relieve or eliminate the pains. On the other hand, value proposition could be understood as something that will contribute to customer ś gains andsuccesses that a customer wants to achieve. Creating a value map will contribute creation of right thing, product or service in stone industry that will satisfy customer´s needs and wants.

So, value proposition for customer, should clearly describe how product or service in stone industry, on which value for customer is built on, satisfies customer ś needs and wants. Also, value for customer should clearly how the product or service in stone industry contributes to the positive outcomes and successes that the customer wants to achieve as well as how the product or service in stone industry helps lessen or eliminate negativities that the customer wants to avoid.

Value proposition and Customer segments are two building blocks of Business Canvas Model.

Anothertwo building blocks that link value proposition and customer segments are Channels and Customer relationships as depicted in Figure 1. These two building blocks are situated between Value proposition and Customer segments building blocks creating right part of the business model canvas.

Customer relationship building block describes what type of relationship each of customer segments expect us to have and maintain with the business. So here it should be described what kind of relationship business develops with customers. It can vary from personal to automated.

Channels building block states through which channels customer segments will be reached to deliver the value and how the channels will be integrated into customer activities so that the channels are convenient to customers.

Below these four building blocks there is Revenue Stream building block which shows how revenue stream will be designed and how a business generate revenue.

To the left from Value proposition building block there are two building blocks Key activities and Key resources. While Key activities states what key activities value proposition requires to be created, key resources building block describes what resources are required to perform activities and to create product or service in stone industry.

On the left to these two building blocks is business model canvas building block Key partners as shown in Figure 1. This building block lists who key partners are and what resources and values key partners will provide. Key partners could be, for example, suppliers and so on, or any partner that will perform business activity that is outsourced from the internal organizational value chain.

Below these three building blocks, Key activities, Key resources and Key partners there is Cost structure building block which describes costs incurred when performing under

designed business model as shown in Figure 1.

It can be seen that the business model canvas focuses both outside the business on creating (and retaining) customers (focus on effective side of the business to do the right thing) and it is inside oriented as well on doing in the right way with minimal costs and the highest possible productivity (focus on efficient side of the business, maximizing productivity and lowering costs).

As said earlier, successful business in stone industry is reflected in the ability to have these two opposite sides of the business, effectiveness and efficiency in balance, with the aim to both achieve both higher effectiveness and higher efficiency. Higher effectiveness means higher revenue, while higher efficiency means lower operations costs.

To be successful in stone industry businesses should be both effective and efficient, and this is where the complexity arises. The key is to have these two opposite concepts in balance which is not easy at all.

Sustainable businesses in stone industry are only businesses that proactively "create a customer" through innovation and marketing as two basic business functions, taking care about cost side of the business.

Building energy performance assessment as a function of stone facade properties

Implementation of statistical tools in modeling of energy performance of building is not fully explored in practice. In presented analysis, design of experiments methodology is used to model specific energy need for heating for one representative building in Bosnia and Herzegovina.

Since, stone is traditionally used as a building material in Bosnia and Herzegovina, two different types of external walls are examined. First model considers that building external walls are solely made of stone, while second model considers that brick walls are insulated and covered with stone claddings. Other building architectural properties are taken into consideration, as well as climatic region. It is well known that windows thermal properties have impact on building energy performance, so different window types are taken into account as factor in this analysis. Climatic data varies between different regions too, where south region is characterized by dry and hot summers and mild winters without snow, but with need for heating during winter. North and central regions are characterized by cold winters with higher energy need for heating than in south region. As a result of variation of selected factors, building energy need for heating varies too. Hence, development of mathematical models for fast estimation of energy need for heating is very useful, especially in cases where various building architectural properties and different climatic regions are considered.

4.1 Representative building of multi-family houses in Bosnia and Herzegovina

There are 19.254 of multi-family houses in Bosnia and Herzegovina, with total of 9.949.396 m2 of net heated area. As one of the statistical representative of this category, multi-family house with net heated area of 561,99 m2 and building compactness ratio of 0,71 is selected and shown in Figure 4.1. Net heated volume of building is 1.405 m3, and gross heated volume is 1.644 m3.

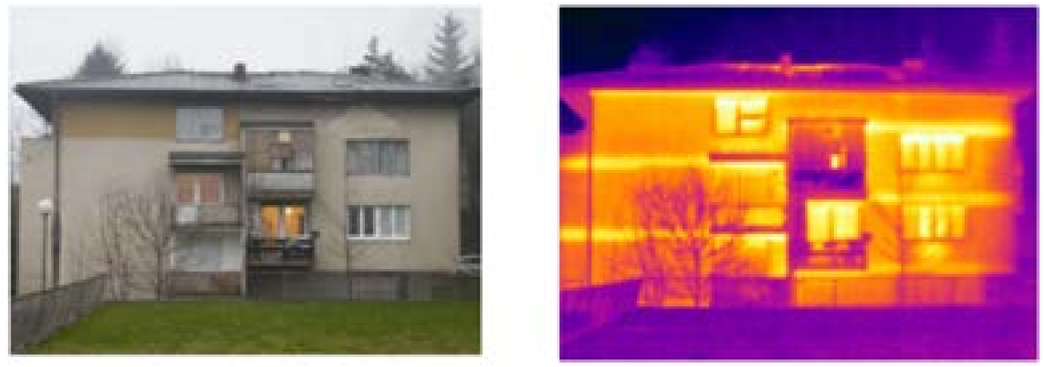


Figure 4.1: Visualization and therman image of typical multi-family house

Buildings in this category usually have ground floor + 1 to + 3 floors. External walls are predominantly made of solid brick, without thermal insulation and with plaster finish. Hip roof is without thermal insulation, supported by wooden beams and covered with corrugated roof panels. Windows are made of wood or PVC, with poor thermal performance. Tenuous thermal characteristics of building envelope results in poor building energy performance, which significantly increases value of energy need for heating.

Thermal transmittance of building envelope is shown in Table 4.1. As an example, thermal transmittance for new building and climatic region north, is set to a maximum value of 0,35 W/m2K. Therefore, it is visible from values presented in Table 4.1 that thermal characteristic of building envelope is poor, with high transmission and ventilation losses.

Construction element	Thermal transmittance [W/m^{2}K]
External walls	1,91
Roof/attic construction	3,85 / 3,23
Floor/ceiling toward unheated area	2,51 / 1,23
Windows/doors	2,0; 3,6 / 5,11
Internal walls against unheated staircase	2,32

Table 4.1: Visualization and therman image of typical multi-family house

Energy need for heating is calculated for two largest cities with different climatic conditions; Sarajevo (situated in North climatic region) and Mostar (situated in South climatic region), as shown in Figure 4.2.

4.2 Variation of building envelope thermal characteristic

Variation of building envelope thermal characteristic is shown via thermal transmittance of construction element, as shown in Table 4.2.

Construction element	Thermal transmittance, W/m²K		
	Original state	Modeled state 1	Modeled state 2
External walls	Brick wall, 25 cm  1,91	Stone wall, 25 cm  2,63	Brick wall + thermal insulation + stone cladding 25 cm + 12 cm + 13,5 cm  0,26
Windows/ doors	Wood and PVC frame  3,6; 2,0 / 5,11	Wood and PVC frame  3,6; 2,0 / 5,11	PVC frame/Low-e  1,40

Table 4.2: Thermal transmittance for modelled state

For the purpose of presented analysis, external walls are modified as follows:

Modeled state 1 where it is assumed that wall construction is based on natural stone with same thickness as brick wall. Stone density is □=2000 kg/m3 and its thermal conductivity □=1,4 W/mK.

Modeled state 2 where it is assumed that wall construction is based on original state with brick, where thermal insulation od 12 cm is added with finishing stone cladding of 13,5 cm. Thermal conductivity of insulation is 0,037 W/mK, stone cladding density is □=2500 kg/m3 and its thermal conductivity □=2,8 W/mK.

For the purpose of presented analysis, windows are modified as follows:

Modeled state 1 same windows as in original state with thermal transmittance ranging from 2,0 to 5,11 W/m2K and substantial ventilation losses related to the poor tightness.

Modeled state 2 where it is assumed that all windows are replaced with PVC, double glazed windows, with Low-e coating. Windows tightness is improved and transmission and ventilation losses are reduced.

For modeled state, building annual energy need for heating in kWh/ann is calculated, with variation in climatic data related to different cities (Sarajevo and Mostar). Energy need for heating can be presented in specific value in kWh/m2ann, when divided with net heated area, which serves as an energy performance indicator.

4.3 Statistical analysis

To generate mathematical expression for specific energy, need for heating in function of selected factors, full factorial experiment was designed and performed. Analysis is performed using statistical software Minitab. Information about factors and its levels are shown in Table 4.3. Total of 3 factors (Facade type, Region and Window type), each on two levels are varied, in 8 simulation runs.

Factor	Level	
	-1	1
Façade type	2,63	0,26
Region	Mostar	Sarajevo
Window type	3,6; 2,0 / 5,11	1,40

Table 4.3: Factor information

For each simulation run, factors levels are generated according to Table 4.4, where specific energy need for heating is estimated.

Facade type	Region	Window type	Specific energy need for heating, kWh/m²ann
1	1	1	110,7
-1	1	1	191,8
1	-1	1	57,1
-1	-1	1	106,6
1	1	-1	157,5
-1	1	-1	231,6
1	-1	-1	83,9
-1	-1	-1	129,4

Table 4.4: Experimental Design

Statistical analysis is performed in Minitab using data given in Table 4.4. Result of analysis of variance (ANOVA) is shown in Table 4.5.

Important factors can be determined according to P-Value. All corresponding P-Values less than 0,05 indicate significant factors. It can be seen that factors Facade type, Region and Window type and their interactions Facade type*Region and Region*Window type are significant (marked green in Table 4.5.). Interaction Facade type*Window type is not significant (marked red in Table 4.5.).

Highest impact on specific energy need for heating has Region (contribution 53,43 %), following Facade type with 33,79 % and Windows type with 10,02 %. Joint impact of significant interactions is 2,69 %.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	6	23156,9	100,00%	23156,9	3859,5	3744,12	0,013
Linear	3	22516,9	97,23%	22516,9	7505,6	7281,29	0,009
Facade type	1	7823,9	33,79%	7823,9	7823,9	7590,08	0,007
Region	1	12373,5	53,43%	12373,5	12373,5	12003,62	0,006
Window type	1	2319,5	10,02%	2319,5	2319,5	2250,17	0,013
2-Way Interactions	3	640,0	2,76%	640,0	213,3	206,95	0,051
Facade type*Region	1	454,2	1,96%	454,2	454,2	440,64	0,030
Facade type*Window type	1	15,3	0,07%	15,3	15,3	14,86	0,162
Region*Window type	1	170,4	0,74%	170,4	170,4	165,35	0,049
Error	1	1,0	0,00%	1,0	1,0		
Total	7	23157,9	100,00%				

Table 4.5: Analysis of variance (ANOVA)

Regression equation for calculation of specific energy need for heating, in coded units -1 and +1, is given by following equation:

R-squared for regression model is 99,97%, indicating high accuracy and ability of model to reliably predict specific energy need for heating.

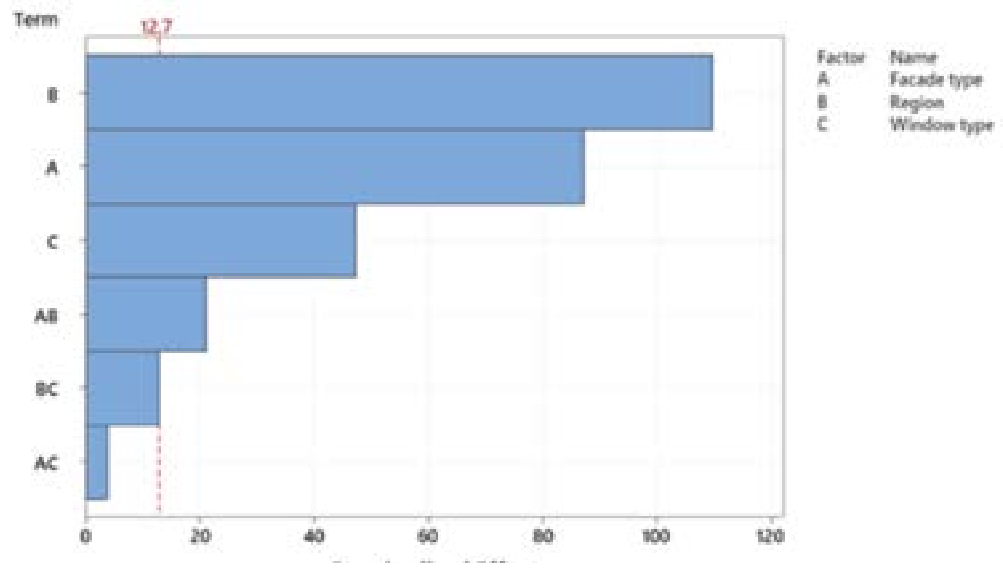
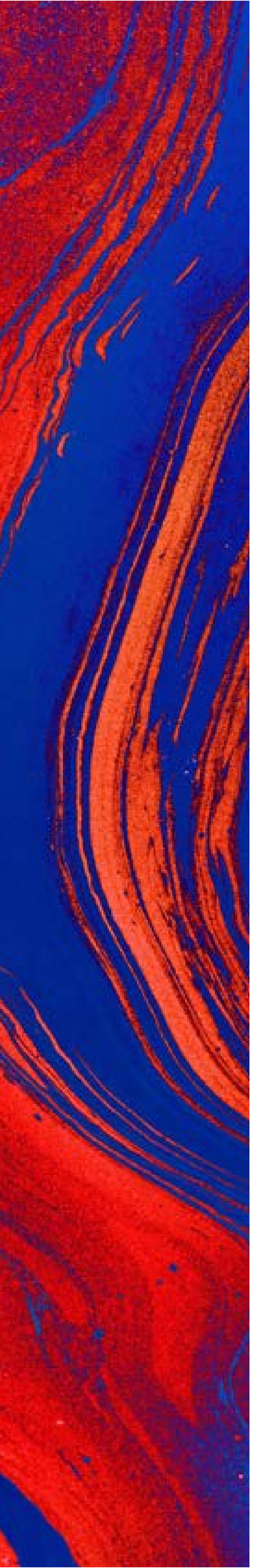


Figure 4.3: Pareto chart of the standardized effects

Pareto chart of the standardized effects, shown in Figure 4.3, is visual representation of impact of factors and interactions and is in-line with conclusions based on ANOVA Table 4.5. All bars, representing factors, longer than critical value presented by red line are significant. It can be seen that highest effect has Region, followed by Façade type, Window type and interactions, Facade type*Region and Region*Window.

Main effect plot for specific energy need for heating, shown in Figure 4.4, is visual representation of effects of individual factors on specific energy need for heating. Inspecting the slope of lines shows positive or negative change of specific energy need for heating when factor is changed from level -1 to +1. it can be concluded that changing of Façade type from level -1 to +1 result in decrease of specific energy need for heating. This is expected since improved thermal properties of Facade at level +1 result in decrease of specific energy need for heating. Influence of region is positive, therefore changing the climatic Region from -1 (South climatic region) to +1 (North climatic region) result in increase



of specific energy need for heating. Changing of Window type from level -1 (high thermal transmittance and ventilation losses) to +1 (low thermal transmittance and ventilation losses) result in decrease of specific energy need for heating. Improved thermal properties of Windows at level +1 result in decrease of specific energy need for heating.

4.4 Conclusion

Presented analysis has shown that design of experiments can be successfully applied in modeling of e building energy needs. In this analysis, energy need for heating is considered, but this methodology can also be applied for energy need for cooling, etc. Design of experiments, applied in modeling of energy need for heating, enables in-depth analysis of factors and its influence. This analysis has shown that it is possible to estimate significant factors and their interactions, as well as their individual effect on response variable. Developed regression equation enables estimation of energy need for heating for various architectural and climatic characteristics of buildings.

Finally, presented methodology can be easily applied on various engineering problems with larger number of factors and its levels.

Figure 4.4: Main effect plot for specific energy need for heating

Circular Economy

Methods of environmental analysis and Life Cycle Analysis

Environmental Product Declarations (EPD). Regulatory developments

Procedure for drafting and issuing Environmental Product Declarations (EPD) of stone

LCA: performance improvement and environmental communication of companies and AIC (Architecture, Engineering and Construction) firms

EPD as a tool for increasing the competitiveness of manufacturers and construction products

Environmental certification systems for sustainable projects

The term sustainable means that it can stand on its own, without depleting natural resources. A world driven by natural resources requires good natural resource management to achieve what is known as sustainable development or meeting the needs of present generations without compromising the possibilities of the future. Sustainable development encompasses three factors: society, economy and the environment.

The basic concept in Circular Mining called Life Cycle Assessment (LCA), is a process that allows us to evaluate the environmental burdens associated with a product, process or activity, identifying and quantifying both the use of matter and energy as waste and emissions to the environment, to determine the impact of that use of resources and to evaluate and implement environmental improvement strategies. It includes the complete cycle of the product, process or activity, taking into account the stages of extraction and processing of raw materials, production, transport and distribution, use, reuse and maintenance, recycling and landfill disposal at the end of its useful life.

METHODS OF ENVIRONMENTAL ANALYSIS AND LIFE CYCLE ANALYSIS

1.1. Introduction to the study of the sustainability

The first explicit definition of sustainable development is found in the Report of the UN World Commission on Environment and Development (WCED), Our Common Future (1987). This document defines sustainable development as: "Development that meets the needs of the present without compromising the ability of future generations to meet their needs".

If we look for more current definitions of sustainable development, today we find a multitude of them. As with any definition, and above all due to the great evolution that industry has undergone since then, this concept has evolved and has been adapted as much as possible. A very interesting definition is the one proposed by the IUCN, the United Nations Environment Programme (UNEP) and WWF in 1991: "Development that improves the quality of life while respecting the carrying capacity of the Earth".

Finally, it is important to differentiate the concept of sustainability from the concept of sustainable development, as it has been used as a simile on numerous occasions (Gómez I., 2019).

The sustainability consists of trying to minimise the number of resources used while maximising the creation of economic, social, and environmental value, achieving a balance between the social, economic, and environmental dimensions.

We also find the concept of eco-efficiency as a remarkable concept. The concept of eco-efficiency was first coined in 1991 by Swiss industrialist Stephan Schmidheiny, spokesman for the Business Council for Sustainable Development (CEDS). In simple terms, the term eco-efficiency is intended to identify the creation of a greater volume of goods and services, optimising their economic efficiency, while at the same time obtaining an ecological benefit that is fundamental for sustainable development. (Hernández, R., 2003).

One of the best-known definitions of eco-efficiency is the one referred to above used by the WBCSD, which states by WBCSD, which states that: eco-efficiency is obtained through the provision of competitively priced goods and services, which are competitively priced goods and services, which meet human needs and provide quality of life, while reducing the quality of life, while progressively reducing ecological impacts and resource use intensity over time. intensity of resource use over their life cycle, to a level at least commensurate with the estimated carrying capacity of the the Earth's estimated carrying capacity (Schmidheiny, Chairman, AG, and WBCSD, 2010).

Figure 1: Sustainability

Another definition is provided by the European Environment Agency, which defines eco-efficiency as eco-efficiency as sufficient decoupling of the use of nature from the economic activity necessary to satisfy human economic activity necessary to meet human needs to enable it to be maintained within carrying within carrying capacities; and to allow equitable access to and use of the environment for present and future generations. of the environment for present and future generations; more well-being with less nature. (EEA, 1999).

In the UNE-EN ISO 14045:2012 standard, we find the concept of eco-efficiency as a quantitative management tool that allows for the quantitative management tool that allows the study of the environmental impacts of the life cycle of a product system. life cycle of a product system together with its value to a product system of interested parties. stakeholders (AENOR, 2012).

The Colombian Business Council for Sustainable Development (CECODES) defines eco-efficiency as a management philosophy that drives organisations to look for environmental improvements that bring parallel economic benefits. It focuses on business opportunities and allows companies to be more environmentally responsible and more profitable. and more profitable. Eco-efficiency fosters innovation and therefore growth and competitiveness.

Eco-efficiency covers a broader field than environmental protection or pollution con-

trol. pollution control. It also aims at the treatment of natural resources, both raw materials and energy inputs at the level of the company itself and not by outsourcing as in the past. outsourcing as was traditionally the case when addressing the issue.

It is important to highlight the difference between eco-efficiency and other sustainable approaches, such as cleaner production. In the case of eco-efficiency, importance is given to the use of natural resources as an element of economic development (Leal J., 2015).

There are three main strands to this:

- The use of natural resources.
- The provision of ecological services to contribute to the life of the ecosystem and absorbing waste from economic activity.
- The protection of biodiversity.

1.2. Life cycle Assessment

Life Cycle Analysis (LCA) provides a simplified model of a given production system and its associated environmental impacts.

According to ISO 14040 (1997): "LCA is a technique for determining the environmental aspects and potential impacts associated with a product by: compiling an inventory of the relevant inputs and outputs of the system; assessing the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study".

The Society of Environmental Toxicology and Chemistry states that: "LCA is an objective procedure for assessing the energy and environmental loads of a process or activity by identifying the materials and energy used and the discharges to the environment. The assessment is carried out over the entire life cycle of the process or activity, including extraction and treatment of raw materials, manufacture, transport, distribution, use, recycling, reuse and final disposal (SETAC, 1993).

The life cycle consists of the set of stages of a product from the extraction and processing of raw materials, production, transport, marketing, use and maintenance to final management when it reaches the end of its useful life.

The sum of all inputs of matter and energy (inputs) and outputs of waste, co-products and emissions (outputs) constitutes the environmental impact of the product.

The objectives of Life Cycle Assessment are:

To provide information, as complete, objective and transparent as possible, on the interactions of the product, process or activity with the environment.

Contribute to the understanding of the environmental consequences caused by human activities.

Figure 2: Stages of the product Life Cycle. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Anticipate negative consequences of decision-making and enable the identification of opportunities for environmental improvements.
To facilitate constructive dialogue between different sectors of society concerned with environmental quality.

In its most widely known expression, Life Cycle Assessment consists of 4 steps:

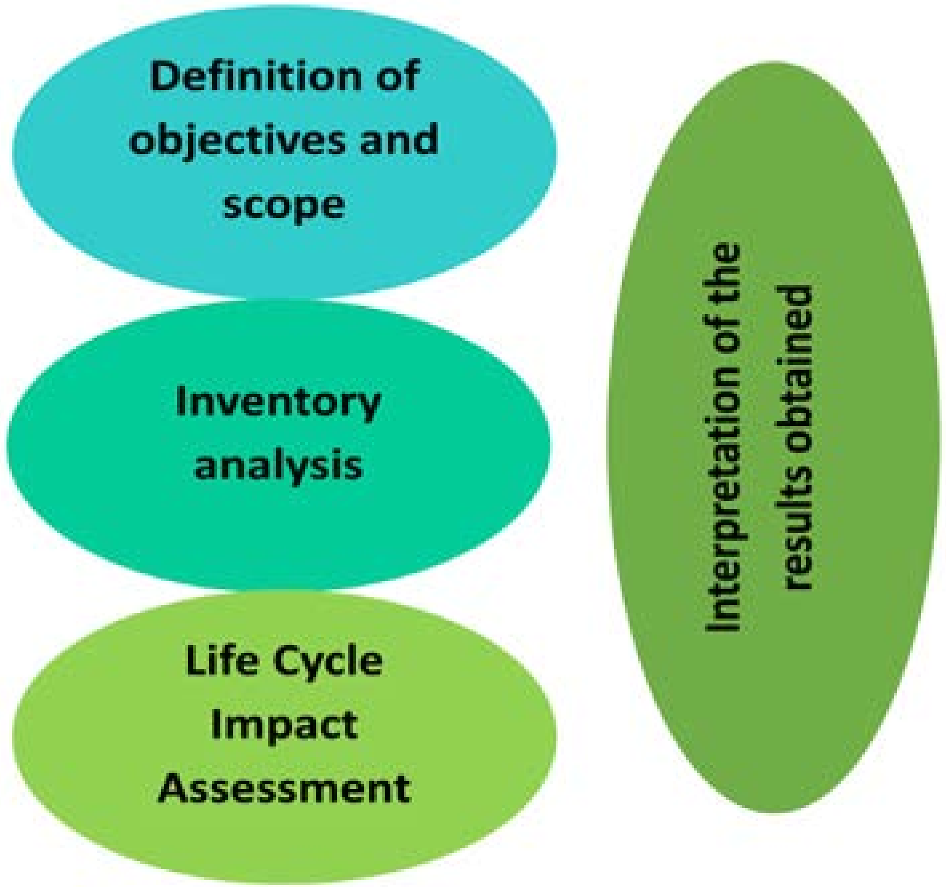


Figure 3 Life Cycle Assessment Framework. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Definition of objectives and scope. Defines the objective and intended use of the study, as well as the scope according to system boundaries, functional unit and life cycle flows, required data quality, and technological evaluation parameters.
Inventory analysis. In this step, the material and energy balances across the different components of the life cycle are developed.

Life Cycle Impact Assessment. This is the phase in which the inventory of inputs and outputs is mapped to indicators of potential environmental impacts on the environment, health, and availability of natural resources.

Interpretation of the results obtained. In this phase of the LCA, the results of the Life Cycle Inventory Development and Life Cycle Impact Assessment are interpreted according to the initial objective and scope. Therefore, improvement measures that allow the reduction of the most relevant impacts must be identified and evaluated.

In view of the stages that make up the life cycle, it is common to find different scopes in the development of a LCA, the most common being (Haya L., Esperanza, 2016):

Gate to gate: this only considers the activities (production process) of the company to which it is applied.

Cradle to gate: it takes into consideration from the extraction and from the extraction and conditioning of raw materials to the company's production process.

Gate to grave: considers the company's production process and covers the waste management phase of the product.

Cradle to grave: studies from the packaging of raw materials to the final waste management (recycling or other).

Cradle to cradle: considers the entire life cycle of the product, from the packaging of the raw materials to the final waste management (recycling or other). from the packaging of raw materials until the product, after being out of use, is reintroduced into the market. out of use, is reintroduced into the same or another production process.

Environmental Product Declarations (EPD). Regulatory developments

2.1. Introduction to Ecolabelling.

Ecolabelling is a method of assessing and reducing the environmental impacts of products. This environmental management tool provides numerous advantages such as:

- It helps to sell by providing the eco-label differentiation from the competition and facilitates the entry into new markets according to the needs and expectations detected with its ISO 9001 certificate.

- It improves the reputation of the organisation and its brand image as it conveys a concern for environmental respect.

- Reduces risks by using components with proven validity in terms of eco-label requirements.

- It is compatible with other ISO labels and certificates such as ISO 14001 and recognitions such as EMAS verification.

- Provides consumers with accurate, science-based product information.

- It is a voluntary assessment process.

Applying for an eco-label for a given product involves certification of compliance with certain environmental requirements that the product significantly improves its environmental aspects throughout its life cycle.

The standards that regulate this type of labelling belong to the "ISO 14020 - Ecolabels and environmental declarations" family and we can distinguish between three types of labelling:

Figure 4 EU Ecolabel. (Source: www.ecolabel.eu)

- ISO 14024: Type I ecolabelling.

Type I ecolabels are environmental certifications that consider the life cycle of the product/service. They are third-party verified by a governmental or non-profit body. They are useful for consumer products and can use LCA to establish performance thresholds to be met for different product categories.

Some of the most widely used Type I ecolabelling schemes in Spain are: AENOR Medio Ambiente (Spain), Disntitu de Garantia de Qualitat Ambiental (Catalonia), Ecolabel (European Union) and Der Blaue Engel (Germany).

- ISO 14021: Type II Ecolabelling.

These are declarations on environmental information made by the manufacturer and therefore have low credibility. They provide information on only one environmental aspect and are usually visible on the product.

- ISO 14025: Type III environmental declarations.

Environmental declarations are made by third parties and are based on the UNE-EN-ISO 14040 standard. It is a quantitative declaration of environmental impact indicators. This type of ecolabel provides objective information based on the Life Cycle Analysis of the product without entering into assessments of whether the product is good or bad.

The environmental product declaration is a voluntary statement indicating qualified environmental aspects and data of a product. and qualified environmental aspects and data of a product. In ISO 14025 we can requirements to be included and the default parameters to be used can be found in ISO 14025. to be used.

A EPD can therefore be classified as an "eco-label", although its main difference from other regulated schemes is that it is a voluntary product label. difference compared to the rest of the systems regulated by the ISO 14020 family of standards is that an environmental environmental product declaration does not define environmental requirements or minimum values to be fulfilled, but rather requirements or minimum values to be met, but rather the results of the LCA study carried out on the product are LCA study carried out on the certified product in order to provide an image of its environmental performance. environmental performance of the product.

Whether or not a product has an EPD does not make it environmentally better or worse than a product that does not have an EPD. a product that does not have an EPD, as the purpose of an EPD is not to identify environmentally friendly products. products. Its main purpose is to provide information on the environmental performance of the product to allow comparison with other products. The main purpose of an EPD is to provide information on the environmental performance of the product to allow comparison with other similar products.

The environmental product declaration is a detailed report with technical information.

Within the environmental impact assessment indicators provided in EPDs, we can distinguish between we can distinguish between:

- Environmental Impacts: Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Ozone Layer Depletion Potential (ODP), and Ozone Depletion Potential (ODP), Acidification Potential (AP), Acidification Potential (AP), Ozone Depletion Potential (ODP), Acidification Potential (AP). (AP), Eutrophication Potential (EP), Tropospheric Ozone Formation Potential (TOPP), Ozone Depletion Potential (ODP), Acidification Potential for ozone formation potential (POPC), abiotic resource depletion potential for non-fossil resources (ADP-ADP) and non-fossil resources (ADP-elements) and abiotic resource depletion potential for fossil resources (ADP-elements). abiotic resources for fossil resources (ADP-fossil fuels).

- Resource use: use of renewable primary energy, use of non-renewable primary energy, use of secondary materials, use of secondary materials, use of secondary materials, use of secondary materials, use of secondary materials. renewable primary energy use, non-renewable primary energy use, secondary materials use, renewable secondary fuels use, non-renewable secondary fuels use and net use of running water resources. water resources.

- Waste category: hazardous waste landfilled, non-hazardous

waste landfilled, and radioactive waste landfilled discharged.

- Other output streams: components for reuse, waste for reuse, waste for disposal, waste for reuse, waste for disposal.

2.2. Regulatory development of the EPDs

For EPD, ISO 14025 must be followed, and for LCA, ISO 14040 and ISO 14044 must be followed. For some products it may be the case that the different EPD/ EPD Certification Programmes have created Product Category Rules (PCR). In these cases, the PCR will be the reference document indicating how to perform the LCA for that type of product, and what content the EPD will have to show.

The International Standardisation Organisation (ISO) standardised (1990s) a systematised working structure for life cycle analysis, giving rise to the standards:

UNE EN ISO 14040: Environmental Management. Life Cycle Analysis. Principles and reference framework.

UNE EN ISO 14041: Environmental Management. Life Cycle Analysis. Definition of the objective and scope and inventory analysis.

UNE EN ISO 14042: Environmental Management. Life Cycle Analysis. Life Cycle Impact Assessment.

UNE EN ISO 14043: Environmental Management. Life Cycle Analysis. Interpretation of the Life Cycle.

However, in 2006, technical revisions were implemented and the previous standards were cancelled and replaced by:

UNE-EN ISO 14040. Environmental Management. Life Cycle Assessment. Principles and reference framework.

UNE-EN ISO 14044. Environmental Management. Life Cycle Assessment. Requirements and guidelines.

Although LCAs should cover the same stages, the level of de-

For this reason, up to three types of LCA can be distinguished:

Conceptual LCA: focuses rather on a qualitative study to identify the most significant potential impacts, so the data used are very general.

Simplified LCA: takes only generic data into consideration and covers the Life Cycle in a superficial way, followed by a simplification, where the focus is on the most important stages, and an analysis of the reliability of the results.

Full LCA: a detailed qualitative and quantitative analysis is carried out.

In the Life Cycle Assessment of a product according to ISO 14040:2006, four phases are distinguished:

Phase 1. Definition of objectives and scope: Statement of the reasons for carrying out the study and establishing its scope. This is the phase where the reasons and the context in which the LCA will take place are established. Issues such as must be defined:

Functional Unit: measure of the function of a product to which all system data will refer.

System boundary: the components and processes that make up the product system will be specified, delimiting which ones are covered and which ones are left out.

Assignment rules: for when several functions or co-products are developed.

Impact categories: indicate which ones are to be calculated and the calculation methodology.

Quality of the data: in terms of temporal, geographical and technological coverage.

Phase 2. Life Cycle Inventory (LCI): Identifying and quantifying the inputs and outputs (emissions to air, soil, water and waste generation) that can potentially cause an impact during the LCA. This is the data collection phase, where all input flows (consumption of materials and energy) and output flows of the different processes that are part of the system are studied.
In this phase, the guidelines set out in the previous phase regarding allocation rules and data quality requirements are followed.

Phase 3. Life Cycle Impact Assessment (LCIA): Stage in which an inventory of inputs and outputs is established. Objective: to classify, characterise and assess the significance of the impacts generated.

Classification: all inputs and outputs should be classified according to the type of impact they may have on the environment in different impact categories. In general there are two types:

o Midpoint: those impact categories that focus on the amount of resources consumed and waste generated per unit of product,

o Endpoint: those impact categories that address the consequences of interventions on the environment.

Characterisation: by means of characterisation factors, each input and output is transformed by calculating the contribution of each, relative to the impact category considered (e.g. CO_2 equivalent emissions).

Phase 4. Interpretation of results: Combination of LCI and LCIA results to draw conclusions and recommendations. This phase should include identification of significant issues, assessment, conclusions and recommendations.

2.3. Reference standards for EPDs

ISO 14040. Environmental management. Life cycle assessment. Principles and framework Describes the principles and framework for LCA.

ISO 14044. Environmental management. Life cycle assessment. Requirements and guidelines Sets out the details of the LCA methodology, describing the processes of life cycle inventory compilation, environmental impact assessment and interpretation of results.

ISO 14025. Environmental labels and declarations. Type III environmental declarations. Principles Sets out the principles and specifies the procedures for developing type III environmental declarations (EPD) programmes, as well as the general procedure for creating EPDs and PCRs.

ILCD HANDBOOK. A handbook to provide guidance on how to carry out an LCA.

The European Life Cycle Assessment Platform, through the Joint Research Centre - Institute for Environment and Sustainability of the European Commission in cooperation with DG Environment, published this handbook in March 2010.

The handbook consists of a series of technical documents and is designed to serve as a guide authorised by the European Commission to assist companies and environmental policy makers in establishing LCA as a reference methodology for measuring the environmental impact of a product/service/activity. It is part of the European Commission's action to promote sustainable consumption and production patterns.

Procedure for drafting and issuing Environmental Product Declarations (EPD) of stone

3.1. EPD Programme Administrators

Certification programmes specify for different product groups a more detailed way of performing LCA and EPD. They are created according to the requirements set out in UNE-EN ISO 14025 and develop specific rules for each type of product included in the PCR.

The programme administrators define the RPC under which LCA studies are to be carried out and the information to be shown in the EPD for a particular product type, in more detail than in ISO 14040/14044 (LCA) and 14025 (EPD). Recently, there has been widespread harmonisation of the content of these PCR between different EPD certification schemes, so that the PCR are compatible.

The Product Environmental Footprint (PEF) is a Life Cycle Assessment (LCA) based method to quantify the relevant environmental impacts of products (goods or services). It builds on existing approaches and international standards, and is part of the "Single Market for Green Products Initiative" that is initiated by the European Commission.

Here are some programme administrators:

Product Environmental Footprint. The aim of the PEF is to create a common language and method for calculating a product's environmental footprint, which is the foundation for a set of specific rules. These rules are called the Product Environmental Footprint Category Rules (PEFCR), and are a common approach across the EU , normally created at an industry level.

Figure 5 Product Environmental Footprint.

EPD. EPDs signal a manufacturer's commitment to measuring and reducing the environmental impact of its products and services and report these impacts in a hyper-transparent way. With an EPD, manufacturers report comparable, objective and third-party verified data that show the good, the bad and the evil about the environmental performance of their products and services.

When developing an EPD, the environmental performance of the product shall be described from a life cycle perspective by carrying out a life cycle assessment (LCA) of the product. The results of the LCA study and other information mandated by the reference PCR and General Programme Instructions shall be compiled in the EPD reporting format. The EPD shall then be verified by an approved independent verifier before being registered and published at the International EPD System via our EPD Portal.

Figure 6: EPD System

ECO Platform. A main objective of the Association is to promote and to contribute to the sustainable development, including a low-carbon economy and resource efficiency in the construction sector, by coordinating the development and provision of credible and scientifically correct data from products.

ECO Platform aims for mainstreaming life-cycle assessments (LCA) for buildings and infrastructure projects by provision of reliable product data in an affordable and effective way.

Specific product data in form of verified environmental information of construction products, in particular type III declarations called EPD (Environmental Product Declarations) is preferred as data input for building and construction LCA. To close gaps of missing data, for early design stages or product-neutral assessments, generic data is required. ECO Platform aims for consistency of both data categories. Goal is to establish an open international digital data network for building and construction LCA data.

To achieve the overall goals, ECO Platform has defined four main fields of activity and related Mission Statements:

- Advocate of the building & construction LCA Stakeholders

- Quality Manager of verified product data

- Data provider

- Enabler of success

3.2. Development and verification of an EDP

The close relationship between an EPD and an LCA study has already been described and shown: The LCA study of the product/service to be verified will develop a working methodology to assess the environmental impact of the system (from a Life Cycle perspective) and the EPD will translate the content of the study and the results into a document verified by an independent third party.

Therefore, for the development of an EPD, the steps described in the LCA standards ISO 14040 and 14044 and as described in the ISO 14025 EPD development standard have to be followed. In addition, the specific re-

quirements for that product group set out in the reference PCR shall be applied.

Steps for the development of an EPD:

1) Verification of the existence of a reference PCR.

Analysis of the available PCRs through search engines on the websites of the certification programmes.

Appropriate selection of the one that corresponds to the product/service to be verified.

If no applicable RCP exists, contact the programme manager and propose the development of a new PCR.

2) Definition of the objectives, scope and functional unit of the LCA study.

The following are determined: objectives of the study, scope, system boundaries and functional unit to which the whole analysis will refer.

This step is fundamental, as it limits the field of work and the data to be included in the LCA study. To determine these parameters, the specifications of the reference PCR are required.

3) Development of the Life Cycle Inventory of the system.

Compilation of information (in the form of material, energy, waste and emission balances) for each of the life cycle stages of the product/service.

The reference PCR indicates the level of detail of the life cycle stages. This ensures that they are comparable by taking into account the same considerations in the LCI. Fundamental for the verification of the EPD.

Where primary data are not available for certain processes and/or materials, theoretical calculations, estimations or assimilations to data from internationally recognised LCI databases shall be performed.

4) Assessment of the environmental impact.

With the LCI data, the environmental impact assessment will be carried out.

Due to the amount and complexity of the calculations, the assessment is done using LCA software.

The environmental information that the reference CPRs require to be displayed in the EPD will determine the software to be used.

The environmental results shown in an EPD (separated into life cycle phases) may vary from one PCR to another, depending on the particularities of the product type.

5) Drafting of the LCA report.

The information in an EPD does NOT include everything required for a full LCA report according to ISO 14040 and 14044.

We consider that an EPD is a communicative instrument as well as a technical one, it has to be able to convey the most relevant environmental information of the product/service to the stakeholders. The EPD is therefore a summary of the LCA study formatted in a communicative format so that it is accessible to non-experts in LCA.

A full LCA report needs to be written in order to subsequently compile

data, estimates, details and results of the study.

6) Drafting of the EPD.

Extraction and adaptation of the information from the LCA study to draft the EPD. The sections, environmental information, levels of detail... of the EPD will comply with the reference PCR.

Normally, certification programmes do not pre-establish a specific format or layout for the EPD.

Due to the communicative nature of the EPD, it is an excellent mechanism to present a product and convey information about its environmental profile and benefits.

It is advisable to involve the company's communication and marketing department in the drafting of this EPD, in order to adapt the content to the company's corporate image.

7) Verification of the EPD.

Once the product's EPD has been drawn up, the issuing of the verification certificate is processed. Each certification programme has its own procedure and its own network of approved auditors.

Compliance with the requirements of the LCA standards ISO 14040 and 14044 and the EPD standard ISO 14025 is checked, in addition to the requirements of the reference PCR.

The EPD verification process consists of two steps: documentary review and verification audit.

The approved auditor shall check:

-The origin of the data collected for the LCI and the LCA study from the point of view of the veracity, traceability and reliability of the data.

-The environmental impact assessment methodology used.

-The presentation of the environmental profile and the information required by the PCR in the LCA report and the EPD.

-The consistency and adequacy of additional environmental information, if any.

LCA: performance improvement and environmental communication of companies and AIC (Architecture, Engineering and Construction) firms

4.1. Industry and sustainability

Life Cycle Assessment (LCA) is presented as an excellent tool to communicate and improve the environmental aspects of products, services and organisations in a verifiable, scientific and accurate way, in order to promote and satisfy the demand of those consumers who demand products and services that cause less damage to the environment and enable organisations to reduce their consumption of materials and energy.

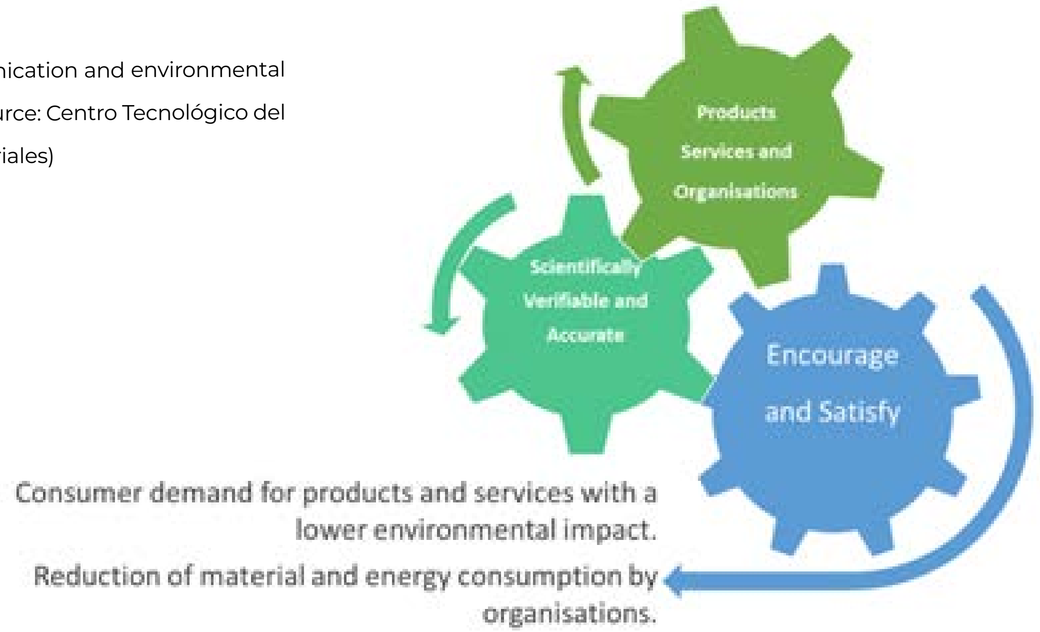


Figure 7: LCA Communication and environmental improvement tool. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

It is also interesting to mention the term "greenwashing". This term refers to practices used by companies to present products and/or services as environmentally friendly without necessarily being so. It is a "make-up" to give a false idea about something that in reality is not as "green" as it is made out to be, nor does it reduce the life cycle impact of the product or service.

Greenwash is an evolution of the traditional concept of whitewash or image bleaching:

Highlight the culturally positive values of companies or institutions.
Improve or clean up their image in order not to lose or regain clients.
Greenwashing can be recognised in several ways:

Ambiguous language: terms or words without a clear concept or rationale. Example: friends of the environment.

Green products: frequent in cleaning companies, products with green colours and images of nature and "freshness" or cosmetics offer an image of "perfect health" that does not correspond to the pollution they produce in their production.

Suggestive images: that indicate to think about sustainable production.

Irrelevant messaging: emphasising the small and unique green attribute of the product.

Best in class": claiming to be significantly more sustainable or green from their perspective is widely used in annual reports emphasising that "we are the most sustainable" or "we have polluted less than other companies".

Imaginary and dangerous friendships: large companies may have divisions or "sub-companies" that do comply with sustainability and environmental standards ("green" image) but present a producer from another subsidiary of the same company, which complies with sustainability standards.

Without scientific evidence or endorsed by official bodies: trying to avoid those images of polluted environments with which they are normally associated.

This creates the need for companies to communicate their environmental performance in a credible way (avoid greenwashing).

Whether the recipient is a final customer (Business to Customer) or a supplier or industrial customer (Business to Business), or whether it is for internal use, environmental information must have the following characteristics, all of which are satisfied by the LCA: objective and unbiased, transparent, comparable and additive.

4.2. LCA: reduction of the impact of products/ services related to stone sector

The performance of standardised LCA studies: Environmental Product Declarations, Carbon Footprint and Ecodesign, allow the quantification of the environmental impact of the system. This knowledge is the first step to start the process of environmental improvement of the product in a quantified way:

Quantified, objective, rigorous, maximum return on investment

Life Cycle Assessment is an effective tool to establish impact reduction strategies at both product and organisational level.

LCA reduction strategies can be summarised as follows:

Improvement strategies. Different options for progressive improvement are evaluated, compared and those with the lowest environmental impact are selected. The LCA provides reliability and makes it possible to quantify the progress made, allowing for an inductive product improvement process.

Breakthrough strategies. Technological modifications are made, they allow significant savings in the environmental impact of the product. LCA allows the quantification of the improvements brought about by technological breakthroughs, optimising their implementation.

Eco-design. Ecodesign can be defined as a philosophy that seeks to design sustainable products and services that minimise environmental impact throughout the product life cycle, from design to production, use and disposal.

The UNE-EN ISO 14006:2011 standard describes ecodesign as an integrated process within design and development that aims to reduce environmental impacts and continuously improve the environmental performance of products throughout their life cycle, from the extraction of raw materials to the end of their useful life.

LCA is particularly useful in eco-design for:

- The framing of the solutions proposed by the designers.

- The elimination of "false good solutions".

- Validation of final decisions.

- Technical support for the communication of the environmental characteristics of the innovation.

Figure 8: Development process of an Eco-desing project. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

4.3. LCA applied to the stone industrial process

The implementation of **eco-labels** makes it possible to provide information on the environmental characteristics of a product or

Its use aims to:

- Respond to a customer's concern

- Reinforce the brand image

- Standardise communication with buyers

- Respond to a demand from legislation or an attack from competitors.

Whether by conducting LCA studies at company level or by carrying out product carbon footprints, the LCA provides rigorous, objective, scientific and verifiable environmental information on the environmental performance of the organisation. These studies are an unbeatable source of information for the preparation of Corporate Social Responsibility reports, as well as the implementation and maintenance of Environmental Management Systems (ISO 14001 or EMAS).

LCA is an ideal tool for optimising and comparing the environmental performance of industrial processes:

- It provides quantified, scientific and rigorous information for decision making.

- LCA allows comparison of the eco-efficiency of different industrial processes.

- LCA is the basic tool of industrial ecology.

EPD AS A TOOL FOR INCREASING THE COMPETITIVENESS OF MANUFACTURERS AND CONSTRUCTION PRODUCTS

5.1. Objectivity, comparability and credibility of EPDs

The environmental declarations are made by third parties and are based on the UNE-EN-ISO 14040 standard. It is a quantitative declaration of environmental impact indicators. This type of ecolabel provides objective information based on the Life Cycle Analysis of the product without entering into assessments of whether the product is good or bad.

An EPD can therefore be classified as an "ecolabel", although its main difference compared to the other systems regulated by the ISO 14020 family of standards is that an environmental product declaration does not define environmental requirements or minimum values to be met, but rather shows the results of the LCA study carried out on the certified product in order to provide an image of its environmental performance.

Whether or not a product has an EPD does not make it environmentally better or worse than another product that does not have an EPD, as the purpose of an EPD is not to identify environmentally friendly products. Its main purpose is to provide information on the environmental performance of the product to allow comparison with other similar products.

An EPD is an unbeatable tool for objective and transparent decision-making based on the environmental impact of goods and services, making it possible to act on those processes with a greater environmental impact and improve the environmental performance of products and services.

The credibility of an EPD is reinforced by the fact that it is verified by third parties and includes the Carbon Footprint.

5.2. Use of the EPDs

In recent years there has been an exponential increase in the number of EPDs published at international and national level. It is not yet common practice in all countries.

Many products at international level have a EDP available to the customer. The use of internationally standardised methodologies (ISO 14040 and 14044, ISO 14025, UNE-EN 15804 and Product Category rules) entails:

That a single EPD published in a particular country is valid and recognised beyond its national borders.

The customer can obtain comparable information on products manufactured in different parts of the world.

Europe is the world region with the highest implementation of LCA and EPD. Italy, Spain, Sweden and Great Britain are the European countries with the highest number of EPD of construction products.

5.3. Benefits of EPDs

A EPD is applicable to all types of products and services within clearly defined product categories. EPDs are designed to meet the various information needs within the supply chain and final products, both in the public and private sector, as well as for more general purposes in information and marketing activities. EPDs add new market dimensions by reporting on the environmental performance of products and services, with a number of key characteristics that give rise to a number of benefits:

For the organisations developing EPDs
For users of EPD information Para las organizaciones que desarrollan las DAP

Consulting an EPD provides information based on verified facts and data on the environmental performance of products and services and can be used as a source of information for various purposes.
The EPDs have got a lot of applications:

Marketing.

Environmental communication to suppliers (B2B) and end consumers (B2C) to be attached to the technical documentation of the product.

Source of quantified, robust and verified information on environmental management systems and Corporate Social Responsibility reports.

Obtaining points in environmental certifications of LEED, BEEAM, and VERDE buildings.

Compliance with regulations.

It opens the door to improving the environmental performance of the product: the implementation of an EPD makes it possible to identify the processes (material and energy) with the greatest impact, an essential first step for analysing proposals for improvement at those points in the life cycle with the greatest potential.

Export aid: specially to developed countries.

5.4. Carbon Footprint of the natural stone

The Carbon Footprint, defined in a very general way, represents the amount of greenhouse gases emitted into the atmosphere from the production or consumption of goods and services (Pande et al., 2010;

Figure 9: Carbon Footprint by Dexter Fernandes (via Pexels)

Wiedmann, 2009), and is considered one of the most important tools for quantifying greenhouse gas emissions.
Greenhouse gases, as defined in the Kyoto protocol in 1997, form a permanent layer in the middle of the atmosphere that prevents all solar radiation that is returned by the earth from escaping, thereby causing the temperature under the layer to rise.

The carbon footprint of a product or service is analysed throughout its entire life cycle. From the extraction of raw materials, processing, manufacturing, distribution, including use and end of life.
The difference in emissions between the most developed, developing and lower income countries ranges from 12 tonnes per capita per year for the richest countries to 1 tonne for the lowest income countries.

There is therefore a direct relationship between carbon footprint and wealth, just as there is a direct relationship between carbon footprint and global temperature rise. From the Industrial Revolution until now the concentration of CO2 in the atmosphere has risen from 280 ppm to 360 ppm and may reach 750 ppm by the end of this century. The best estimates available to date indicate that the average temperature may increase by 1.5 to 6 degrees Celsius by 2100.

According to experts, stabilising the concentration of CO2 in the atmosphere at any level would require cutting CO2 emissions to half of what they are now. Even if CO2 concentration is stabilised, temperature rise and sea level rise will continue for hundreds of years.

5.5. Calculation and international standards of HC

Carbon Footprint approaches differ according to the intended scope: Product or service, corporate, staff, events, territorial, sectoral.

To calculate the carbon footprint of a product, the GHGs emitted during the entire life cycle of a product are measured: from the extraction of raw materials, through processing and manufacturing and distribution, to the use and end-of-life stage (deposit, reuse or recycling).

We can distinguish between direct emissions and indirect emissions:

Direct GHG emissions: These are emissions from sources owned or controlled by the organisation. In a very simplified way, they could be understood as emissions released on-site at the place where the activity takes place, e.g. emissions due to the heating system if it is based on the burning of fossil fuels.

Indirect GHG emissions: These are emissions that result from the organisation's activities but occur at sources owned or controlled by another organisation. An example of an indirect emission is the emission from electricity consumed by an organisation, the emissions of which have been produced at the location where the electricity was generated.

CF= Data Activity x Emission Factor

Figure 10: Carbon footprint calculation formula.

The activity data is the parameter that defines the degree or level of the activity generating the GHG emissions. For example, amount of natural gas used in heating (kWh of natural gas).

The emission factor (EF) is the amount of GHG emitted per unit of the parameter "activity data". These factors vary depending on the activity concerned. For example, natural gas consumption for heating, the emission factor would be 0.202kgCO2eq/kWh of natural gas.

As a result of this formula we will obtain a given amount (g, kg, t, etc.) of carbon dioxide equivalent (CO2eq).

Emission factors are probably the most important element when accounting for emissions for verification by an external party or for reporting of results.

This is because GHG emissions vary according to the region where the activity takes place, but even more important is the source that provides the data.

Some standards and methodologies for the calculation of an organisation's CF:

GHG Protocol. Establishes an objective, efficient and accessible HC calculation methodology. It proposes an alternative HC calculation of an organisation, a product, a service, and an offset project, additional and supporting documentation.

Developed by:

World Resources Institute.

World Business Council for Sustainable Development

Protocols most commonly used internationally to quantify and manage GHG emissions.

UNE-ISO 14065: 2012. Requirements for bodies performing validation and verification of greenhouse gases, for use in accreditation or other forms of recognition.

GREENHOUSE GAS PROTOCOL

UNE-ISO 14069: 2013. GHG quantification and reporting for organisations. It provides guidance for the implementation of ISO 14064-1.

Figure 12: ISO Logo

IPCC 2006 GHG Workbook. A comprehensive guide to calculating GHGs from different sources and sectors, including a detailed list of emission factors. This guide was developed to provide guidance for quantifying GHG emissions from national inventories. If specific emission factors are not available, the IPCC 2006 GHG Workbook provides generic emission factors that can be used to calculate an organisation's GH.
GRI Indicators (Global Reporting Initiative). Their objective is to establish a common global framework, with a uniform language and common parameters to communicate sustainability issues in a clear and transparent way through so-called Sustainability Reports.

The aforementioned Reports include a variety of information, including Performance Indicators: indicators that provide comparable information on the organisation's economic, environmental and social performance.

Figure 13: IIPCC 2006 GHG Workbook.
(Source: www.ipcc.ch)

Figure 14: Global Reporting Initiative logo. (Source: https://www.glo-balreporting.org/)

ENVIRONMENTAL CERTIFICATION SYSTEMS FOR SUSTAINABLE PROJECTS

6.1. Introduction to the environmental certification of projects.

The Environmental Certification of buildings is a voluntary certification, whose energy targets exceed those established in current regulations, which means that certified buildings have added value in terms of sustainability.

They guarantee a quality standard in terms of building performance, in aspects such as :

- Water consumption

- Energy consumption

- Occupant comfort

- Use of environmentally friendly materials.

We understand sustainable building as a process in which all the agents involved participate:
Property, planners, builders, facultative team, material suppliers, administration, etc...
It is a process in which functional, economic, environmental, and quality considerations are considered to produce and renovate buildings and ensure that buildings remain:

- Durable, functional, accessible, comfortable, and healthy.

- Efficient with the use of resources (consumption of energy, materials, water, ...), favouring the use of renewable energies, using environmentally friendly materials (recyclable or reusable) and not containing hazardous products.

- Respectful of their environment and neighbourhood, local culture, and heritage.

- Economically competitive, especially considering the long-life cycle associated with buildings, which involves aspects such as maintenance costs, durability, and resale prices of buildings.

The different methodologies, tools and systems for assessing the environmental sustainability of projects identified in the market have been distinguished into the following three types:

- Sustainability assessment systems

- Standards in sustainable buildings

- Assessment software

6.2. Reference systems for environmental certification.

At the European level, the most important reference systems for environmental certification are:

- BREEAM

- HQE

- ITACA

- Verde

BREEAM (Building Research Establishments Assessment Method), is a certification method, which trains specific assessors to be able to carry out the assessments, while the certification is

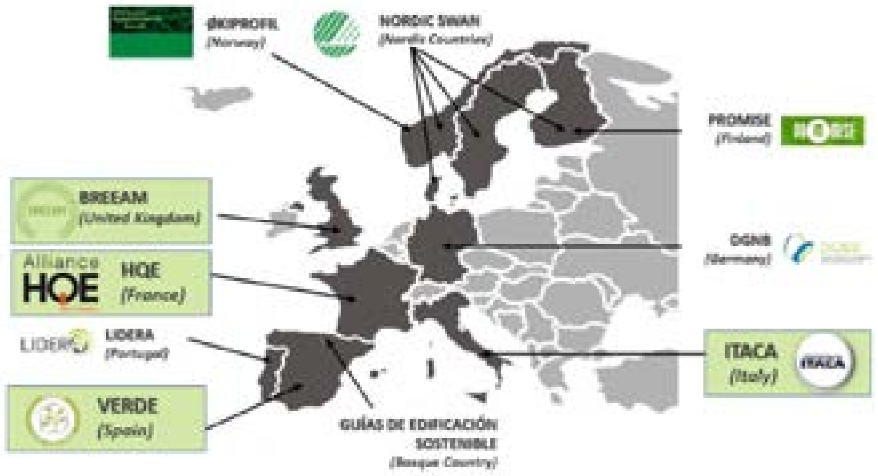


Figure 15: IEuropean reference systems for environmental certification. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Figure 16: IBREEAM logo. (Source: https://bregroup.com/products/breeam/)

carried out by BRE Global.

Managed by the BRE Trust (formerly the Foundation for the Built Environment), through its subsidiary companies BRE Global Limited and FBE Management Ltd.

HQE (Haute Qualité Environnementale) certified is owned by AFNOR (French Association of standardisation and ISO representative) and certifies tertiary and residential buildings.

The French association HQE (Haute Qualité Environnementale - High Environmental Quality) defines a set of standards for environmentally friendly buildings. The main one is the HQE procedure.

This certification system is valid at national level and allows the certification of residential and non-residential buildings.

NFORMATION GATHERING	The design team / The building manager / The BREEAM assessor
CARRYING OUT THE EVALUATION	BREEAM-licensed assessors
THIRD PARTY VERIFICATION	BRE Global
CERTIFICATION	BRE Global

Figure 17: BREEAM summary table. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

Figure 18: HQE logo. (Source: https://www.behqe.com/cerway/essentials#)

INFORMATION GATHERING	The design team
CARRYING OUT THE EVALUATION	Accredited professionals for the phases "Building Design" and "Construction/Execution".
THIRD PARTY VERIFICATION	Authorised consultants, on-site inspectors and professional diagnostics
CERTIFICATION	It is carried out by AFNOR, through certifying bodies: • Tertiary buildings, CERTIVÉA, a subsidiary of CSTB. • Residential buildings, CERQUAL, a subsidiary of QUALITEL • Single-family dwellings, CÉQUAMI

Figure 19: HQE summary table. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

ITACA (Istituto per l'Innovazione e Trasparenza degli Appalti e la compatibilita ambientale). The ITACA Protocol was developed by the working team consisting of regional and iiSBE Italy representatives. The system is based on the SBTool, adapted to Italy.

Figure 20: ITACA logo. (Source: https://www.itaca.org/nuovosito/index.asp)

INFORMATION GATHERING	The Italian regions are in charge of defining how the certification procedure will work and how accreditations for authorised assessors will be granted.
CARRYING OUT THE EVALUATION	
THIRD PARTY VERIFICATION	ITACA supervises and controls the certification systems and guarantees the quality of the results issued.
CERTIFICATION	In some regions, iiSBE Italy has the status of a certifying body, through the ITC-CNR.

Figure 21: ITACA summary table. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

VERDE. The VERDE tool has been developed by the GBC Technical Committee with the collaboration of the ABIO-UPM Research Group, Institutions and companies associated to GBC Spain, and is based on the SBTool.

VERDE recognises the reduction of the environmental impact of the building being assessed compared to a reference building.

The reference building is always a standard building that strictly complies with the minimum requirements set by standards and common practice.

The VERDE methodology is based on a life cycle analysis approach at each stage of the building process. It differs from the SBTool in that it considers the end-of-life, refurbishment or demolition phase.

Figure 22: VERDE logo. (Source: https://gbce.es/certificacion-verde/)

At the international level, the best known reference systems are:

- LEED

- SBTool

- Casbee

Figure 23: European reference systems for environmental certification. (Source: Centro Tecnológico del Mármol, Piedra y Materiales)

LEED (Leadership in Energy and Environmental Design). It is a voluntary certification programme created by the United States Green Building Council (USGBC). Currently the most popular and widely used system in the world. It´s objectives are:

- Define green building by setting measurement standards.

- Promote integrated design practices.

- Stimulate green competitiveness.

- Generate consumer awareness of green building benefits

To achieve LEED certification, a project earns points by adhering to prerequisites and credits that address carbon, energy, water, waste, transportation, materials, health and indoor environmental quality. Projects go through a verification and review process by GBCI and are awarded points that correspond to a level of LEED certification: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points).

Figure 24: LEED logos. (Source: https://www.usgbc.org/leed)

SBTool (Sustainable Building Tool) is the implementation of the tool known as GBTool. It is used to assess both buildings and projects, allowing the development of certification systems adapted to local characteristics, which is its main feature.

The system allows to parameterise the weights of the different impact categories contemplated in the tool so that it adapts to the region in which it is going to be certified, use or schedules.

international initiative for a Sustainable Built Environment (iiSBE). Its aim is to establish a reliable and comprehensive assessment and classification system for buildings.

Figure 25: iiSBE logo. (Source: https://iisbe.org/iisbe/start/iisbe.htm)

To differentiate buildings according to environmental criteria.

The aim is to provide methods for analysing the environmental performance of buildings.

CASBEE (Comprehensive Assessment System for Building Environmental Eficiency). It is a Comprehensive Assessment System for the Environmental Performance of Buildings, developed in Japan with the support of MLIT (Ministry of Land, Infrastructure, Transport and Tourism).

CASBEE has fewer assessment criteria than other systems, so it may be easy to apply but less developed.

The fact that it is easy to implement facilitates its first use and its regular introduction in the construction world. The intention is that, once it has found acceptance, its requirements will be increased.

Figure 24: CASBEE logo. (Source: https://www.ibec.or.jp/CASBEE/english/)

Higher Education–Enterprise platform for fostering, modernisation and sustainable growth in natural stone industry in Western Balkans.

Project acronym: BKSTONE.

Programme: Erasmus+.

Key Action: Cooperation for innovation and the exchange of Good practices.

Action: Capacity Building in Higher Education.

Action Type: Joint Projects.

Project website: https://bkstoneproject.com/

Lead partner organisation: Universiteti Politeknik i Tiranës, Tirana, Albania.

Project manager: Prof. dr. Alma Afezolli

BKSTONE

- Polytechnic University of Tirana - Albania.
- University Aleksandër Xhuvani, of Elbasan – Albania.
- Eqrem Çabej University of Gjirokastër – Albania
- Galician General Directorate of Education / IES Ribeira do Louro – Spain.
- CTM- Centro Tecnológico del Marmol del Mármol, Piedra y Materiales – Spain.
- University of A Coruña – Coruña.
- Mediterranean University of Podgorica - Montenegro.
- University of Mostar – Bosnia & Herzegovina.
- University of Sarajevo.
- University of Prishtina – Kosovo.
- University of Business and Technology – Kosovo.
- National Technical University of Athens - Greece.
- Universita Degli Studi di Roma La Sapienza - Italy.
- Scuola Edile Padova – Italy.
- Transylvania University of Brasov – Romania.

BKSTONE

Co-funded by the Erasmus+ Programme of the European Union