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Optimization of mining works for the purpose of obtaining and installing the dimension stone of a uniform appearance

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Abstract: Deposits of dimension stone (hereinafter: DS) are mostly of heterogeneous composition and non-uniform properties. For the purpose of exploring the DS deposit, it is necessary to perform certain mining work in order to collect data for the determination of: existence, position and shape of the bed, quantity and quality, and the conditions for exploitation of DS. The position and shape of the deposit have a crucial influence on DS exploitation conditions. Discontinuities of different positions, dimensions and shapes were formed as a result of dynamic and chemical processes in the rocks. The exploitation of DS from the deposit is performed by obtaining as geometrically regular and as large in size blocks as possible. The DS exploitation should be harmonized with the position and shape of the deposit as well as discontinuities for the purpose of obtaining the highest possible exploitation of stone. However, a special requirement of construction is to obtain the DS, primarily of uniform appearance and other properties. Therefore, it is necessary to optimize mining works for the purpose of obtaining and installing DS of a uniform appearance, as described and shown on several examples in this paper.

Keywords: dimension stone, discontinuities, mining works, optimization, appearance, installation

Optimizacija rudarskih radova u svrhu dobivanja i ugradnje arhitektonsko-građevnog kamena ujednačenog izgleda

Sažetak: Ležišta arhitektonsko-građevnog kamena (u nastavku: a-gk) uglavnom su heterogenog sastava i neujednačenih svojstava. U svrhu istraživanja ležišta a-gk potrebno je izvesti određene rudarske radove kako bi se prikupili podaci za utvrđivanje: postojanja, položaja i oblika ležišta, količine i kakvoće, te uvjeta eksploatacije a-gk. Položaj i oblik ležišta imaju presudan utjecaj na uvjete eksploatacije a-gk, Kao posljedica dinamičkih i kemijskih procesa u stijenama su nastali diskontinuiteti različitih položaja, dimenzija i oblika. Eksploatacija a-gk iz ležišta izvodi se dobivanjem što je moguće geometrijski pravilnijih i, po dimenzijama, većih blokova. Eksploataciju a-gk potrebno je uskladiti s položajem i oblikom ležišta kao i diskontinuitetima u svrhu dobivanja što većeg iskorištenja stijene. Međutim, poseban zahtjev građenja predstavlja dobivanje a-gk, prvenstveno, ujednačenog izgleda i drugih svojstava. Stoga je nužno optimizirati rudarske radove u svrhu dobivanja i ugradnje a-gk ujednačenog izgleda, što je opisano i prikazano na nekoliko primjera u ovom radu.

Ključne riječi: arhitektonsko-građevni kamen, diskontinuiteti, rudarski radovi, optimizacija, izgled, ugradnja

1. INTRODUCTION

The profitability of exploitation of dimension stone depends mainly on the geological characteristics of the deposit, physical-mechanical characteristics of the stone, technological solutions, exploitation capacity and aesthetic (market) value of the stone, [10]. Due to often numerous unknowns about the geological composition and structure of the deposit, difficulties arise already with the very idea of starting exploitation. In this connection, the degree of exploration of the deposit plays an exceptional role, i.e. more detailed exploration results in a more reliable engineering economic assessment when designing the exploitation of dimension stone (hereinafter: DS).

The DS deposits in the area of the Dinarides are most often of sedimentary origin and, according to the petrographic definition, they are composed of carbonate rocks (limestones and dolomites) and breccias and conglomerates, which also have a carbonate base with a small portion of clay minerals. Stratigraphically, the age of these rocks ranges from the Lower Jurassic (J_1) to the Upper Miocene (M_3). The rocks are found in stratified, semi-regular (zonal) and irregular (massive) forms, of different thickness, distribution and attitude.

Stratified deposits of DS have different thicknesses, so they can be (considering the exploitation technology): thinly stratified (up to 30 cm), medium stratified (30-80 cm), thickly stratified (80-200 cm) and banked (>200 cm). The stratified deposits are mostly of Dinaric strike and different attitudes: from gently inclined (up to 10°, very rarely) to inclined and steep position (from 10 to about 80°, very often).

Semi-regular deposits of DS represent deposits of conglomerate, breccia, limestone and dolomite, which occur in the form of zones of different thicknesses, extents and attitudes and were formed by diagenetic processes.

Irregular (massive) deposits of DS do not have a pronounced stratified structure because they are changed in relation to their original position by tectonic and diagenetic processes. What is usually preserved is only the extension line (dominant Dinaric strike) of the deposits, which are bounded by faults and sometimes with a continuous boundary of stratigraphic units.

A decisive role in terms of the cost-effectiveness of the exploitation of the DS deposit is played by: the state of preservation (compactness) of rocks, in terms of the degree of fracturing, and the homogeneity of stone, in terms of properties (physical-mechanical and chemical) and uniformity.

The state of preservation (compactness) of rock is directly dependent on its condition, which is manifested through structural elements (faults, bedding planes, joints) and the presence of water. The result of the state of the rock mass, for the purpose of DS exploitation, is the utilization coefficient that directly affects the exploitation costs and thereby the realization of profit, [13], [22].

The homogeneity of stone plays a dominant role in the marketing or installation of stone. However, the DS deposits are often variable both in terms of properties and the appearance of stone. The distribution of stone by uniformity is correlated to the types of stone occurring in the deposits. Practice has shown that the uniformity of stone varies dominantly by the thickness of layers or zones (packages) in the deposit, so that, for example, each stone layer gives a certain type, different uniformity from the adjacent layers. At the same time, a more stable uniformity is registered in thickly stratified or wider zones of rocks of the same type. Observing spatially, the uniformity is less variable or negligible along the strike and laterally (by stratification) and more variable in thickness (perpendicular to stratification).

When installing dimension stone, the dominant (decisive) role is played by the appearance of the stone, where the requirement of a certain regularity when placing (installing) stone elements on buildings is set usually by the client. In the case of exteriors (facades, yards, gardens), stone is usually roughly dressed (rustic), such as: picked, bush hammered,

sandblasted, self-faced, etc., so that there is a greater degree of freedom in the selection of stone, i.e. different requirements can be met by different types of stone (both by color and by format-dimensions and processing). Unlike with the exterior, requirements are much stricter in interiors, so the installation of uniform, finely dressed (polished or ground) stone (in terms of color and structure) is usually demanded. For this reason, selection (separation and storage) of the same types of stone should be planned already in the stage of processing or exploitation.

In technological terms, the goal of any DS exploitation is to achieve the maximum utilization of commercial blocks from the deposit. However, numerous discontinuities (faults, joints, bedding planes) represent the biggest limitation in the realization of this goal and it is necessary to adapt to the existing condition during the execution of mining works, [11], [12]. On the other hand, there is a requirement to obtain blocks of the same type of rock, which is often in contradiction with the usability of the rock mass. In addition to the qualitative requirement, uniformity, there is also a quantitative requirement for the decoration of large areas (buildings), that is, obtaining the same type of stone in sufficient quantity for the realization of the project (decoration of the building).

A cause-and-effect relationship between mining works (exploration and exploitation) and the method of installation of dimension stone follows from all of the above. Therefore, it is necessary to harmonize the development of mining works, above all the extension of the front and the direction of progress, with the market demand, or, the possibility of selecting the types of stone. Otherwise, any deviation from the regular, planned development of mining works is an aggravating factor in the placement and installation of stone.

When choosing a stone, the fact is that one should also take into account the exploitation capacity. A small exploitation capacity (when dealing with several types of stone) has limitations in the selection of stone, while a large exploitation capacity offers a greater possibility of selecting stone for installation.

This paper focuses on the optimization of mining works for the purpose of obtaining and installing dimension stone with a uniform appearance. The following DS deposits from the Dinaric area (limestones, dolomites and carbonate breccias) are used as examples: "Smiraj" near Bosansko Grahovo, "Poljane" near Jajce, "Brestovci" near Knin, "Ljut" on Pelješac and "San" and "Kusačko Brdo" near Široki Brijeg.

2. PRINCIPLES OF OPTIMIZATION OF MINING WORKS AND INSTALLATION OF DIMENSION STONE

Business operations of economic entities depend on many interrelated factors. Mining companies can be started if the following conditions are met:

- source of raw material (mineral raw material deposit)
- technological solutions (feasibility of the project in terms of quality and capacity)
- professional staff (qualified workforce)
- market (demand)
- project financing (source of investments)

The exploitation of DS is specific and different from the exploitation of other mineral raw materials in many ways. Among other things, during the exploitation of DS, it is necessary to preserve the integrity of the rock mass in order to achieve the maximum effect in the processing and placement of the products. In addition to integrity, the uniformity of quality and appearance of DS has a great influence on placement.

The uniformity of the quality and appearance of DS is directly related to the first two conditions, that is, to the raw material source and technological solutions. The possible exploitation capacity of DS is also associated with the same conditions. The correlation between the DS processing and the placement or installation of stone should be added to that.

This results in a necessary consideration (analysis) of the exploitation conditions according to the condition of stone installation. This results in a sequence of events or activities that need to be optimized (implemented) in order to achieve maximum effect or business operations.

The related (cause-and-effect) activities that need to be optimized are:

- Exploration of deposits (prior to exploitation)
- Exploitation of DS (before processing)
- Selection-classification of blocks by stone types (before processing)
- DS processing (before installation)
- Installation of DS

Exploration of DS deposits

The exploration of the DS deposit is based on the project of detailed investigations, which involves the development of a geological map and the schedule of exploration works, according to the strike and dip of the strata (deposits).

On the basis of the exploration works, the structure, shape and spatial position of the deposit are determined (strike, dip direction, dip) which directly affect the development of mining works during the exploitation of DS.

Exploratory drilling and trial exploitation, as well as laboratory and *in situ* tests determine: types and spatial distribution of rocks, quality and quantity of DS. A higher degree of investigations gives more reliable results for further planning of exploitation and placement of DS. One or more types of DS, different in properties and appearance, can be present in one deposit, which reflects both on the exploitation and on the processing and installation of the stone. This therefore indicates the cause-and-effect relationship between mining operations and the processing and installation of DS. For example, if the presence of several types of stone in a deposit is disregarded due to the insufficient level of exploration, this will result in a non-selective approach during exploitation and, consequently, during the processing and installation of stone.

Exploitation of dimension stone

Exploitation of dimension stone is carried out according to solutions from the mining project, which is based on the knowledge presented in the study on DS reserves. Exploitation of DS implies obtaining the largest possible amount of rock in the form of geometrically regular blocks of optimal dimensions. At the same time, maximum attention must be paid to the variability of stone, both in terms of properties and appearance. Depending on the type of rock, spatial position and thickness of the deposit, as well as structural elements (discontinuities), it is necessary to prepare and implement a plan for the development of mining works, that is, to determine the position of the front and the direction of progress of benches. It is also necessary to anticipate technological solutions (machines and equipment) that will achieve maximum effects and capacities for the purpose of optimal exploitation of DS.

The proper program of mining works and selection of appropriate technological solutions should make it possible to classify the rocks by type and quality of DS (classification by integrity and dimensions of blocks).

Taking into account the type of rocks, spatial distribution and dominant (prevailing) discontinuities (stratification, faults and joints), mining works are carried out so that the front of the mining works follows the line of deposit strike where the direction of progress is vertical or parallel to the dominant discontinuities (joints that have the character of a maximum and submaximum), [9], [20].

Dimension stone is obtained by cutting blocks in horizontal or inclined benches, depending on the thickness of rock beds and dip of the deposits (beds), which results in a greater or lesser utilization of stone.

The most favorable result is achieved when the blocks are cut parallel or perpendicular to bedding planes, [7]. Otherwise, the diagonal (triangular) shapes of cut produce blocks that have a lower value in terms of dimensions and appearance and at the same time make it impossible to select the stone.

Selection-classification of blocks by stone types

The absence of a sufficient number of reliable data about the DS deposit results in spontaneous exploitation that has the following negative effects as a result:

- Impossibility to select (choose) the stone according to uniformity
- Low degree of stone utilization (small dimensions of blocks, high variability of types)
- Small exploitation capacity (the most common limitation of the contractor)
- Difficult processing of stone into finished elements for installation

The selection-classification of blocks by stone type directly affects the possibility of selecting the stone that needs to be processed and installed according to the construction design. In order to make a good selection of blocks, by type of stone, the following is necessary, among other things:

- Good knowledge of the deposit: determining the type of stone and shape and extent of the deposit
- Achievement of a large exploitation capacity

Dimension stone processing

The processing of DS is performed in stonemason's workshops, which are usually isolated outside the exploitation fields and are in a certain disharmony with the exploitation plans. Processing of DS is carried out according to two models, namely:

- the "random buyer" model, where the final elements are sold from the warehouse
- the "project production" model, where the blocks are processed according to the customer's order

With small quantities of final DS elements, the performance of mining works has no decisive influence on the processing, on the uniformity as well as on the exploitation capacity.

However, when it comes to large quantities of final elements, there are difficulties with the delivery of stone, if the exploitation capacity is too small and the blocks are not appropriately sorted. That is when deviations occur, and unselected stone that may vary in uniformity of properties and appearance is used for processing and installation due to construction deadlines. This should definitely be avoided since it disturbs the aesthetic impression

Installation of DS

Installation of DS on a building is carried out according to the construction design. The following are defined in the installation design:

- type of stone
- stone processing method
- dimensions of stone elements
- amount of stone elements

Installation of stone (according to uniformity and quality) can be:

- with a regular arrangement of elements (unified-uniform) made of stone of the same type, which is usually required in interiors

- with an irregular arrangement of elements (non-uniform, in terms of appearance and format) made of stones of various types, which is rarely required in interiors and is sometimes acceptable in exteriors

Before the installation of stone, samples are taken (selected) to be used for comparison during and after the construction works. However, the cutting of stone blocks can be by stratification, perpendicular to stratification - with horizontal and inclined strata in relation to the plate format, which ultimately gives a completely different result in terms of the uniformity of stone [7]. If the use of different types of DS is added to that, this creates additional difficulties during installation in the absence of an already selected stone. Therefore, cooperation between all participants is required, from the process of execution of mining works, to the processing and installation of stone, in terms of both quality and quantity.

3. ANALYSIS OF THE DEVELOPMENT OF MINING WORKS AT THE SIGNIFICANT (TYPICAL) DEPOSITS OF DIMENSION STONE FROM THE DINARIC AREA

The area of the Dinarides mainly contains deposits of sedimentary origin composed of carbonate rocks (limestones and dolomites) and breccias and conglomerates, with a carbonate base and a small portion of clay minerals. These deposits occur in different geometric forms: in the form of strata of different thicknesses and in semi-regular (zonal) and irregular (massive) forms.

Mining works in a broader sense comprise exploration and exploitation of deposits of mineral raw materials. The exploration of deposits includes the works aimed at establishing the properties such as: formation, shape, geological structure, structure, position, attitude, and quantity and quality of mineral raw materials. In order to collect data about the deposit, exploratory drilling and trial exploitation, as well as direct observation of the deposit, are carried out. This provides an insight into the state of the rock mass, which makes it possible to create project solutions and plan the development of mining works during the exploitation of the deposit.

The position of deposits and discontinuities (stratification, faults and joints) and the morphology of the terrain predetermine the direction of progress of mining works on the dimension stone deposits, [3].

Exploitation or development of mining works on DS deposits is normally carried out:

- along the strike of the deposit
- according to the dip direction of strata (perpendicular to strike) or of the geological unit (massive)
- along the discontinuities (strata and dominant joints)

When opening an open-pit mine, the key question is: where to start mining works? Exploitation of the dimension stone deposit usually begins on the open rock mass located on the stratigraphically youngest member and topographically highest part of the deposit.

The second question is: how to technologically perform the exploitation process when the requirement of maximum uniformity of appearance of DS is set? The most common method of forming benches is to cut or split blocks (pieces) along approximately horizontal planes, which is logically justified because in this way maximum effects of machines are achieved with the simplest work, [14]. However, when the deposits are inclined by more than 10°, the utilization of rock mass is significantly reduced due to oblique cuts and the uniformity of appearance of the stone is lost. For this reason, the benches are formed along bedding planes, which allows the selection of stone by appearance (aesthetics) and at the same time increases the degree of utilization of rock, [2].

Proposals for the development of mining works and technological solutions for extracting DS on significant deposits in the Dinarides area, for the purpose of optimizing the use of the rock mass and the uniform appearance of stone, are presented in the following.

3.1 Exploitation of stratified deposits of dimension stone

Exploitation of thin to medium bedded deposits (thickness up to about 80 cm) - case of "Smiraj"

The "Smiraj" deposit, located near Bosansko Grahovo, contains thin to medium-bedded, and possibly thick-bedded limestones and dolomites, which occur alternately in gray, brown to black color with scattered calcite veins and lithiotis, [5]. The thickness of the strata ranges from centimeter to meter values. Stratigraphically, the rocks belong to the range from the Lower Jurassic (Lias) to the Upper Jurassic (Malm). The overall package of beds covers several hundreds of meters, but the rocks, affected by tectonics, are structurally disturbed in relation to their original position. The strike and dip direction of the strata are variable over a larger area, but in smaller batches of a few hundred meters, a continuous sequence can be followed. The dip of strata varies, from slightly inclined (about 10°) to steeper ones (20-30°). On part of the "Smiraj" deposit, exploration work started and basic data for the development of mining works were collected (Figure 3.1).

Figure 3.1 Positions of DS beds on the "Smiraj" deposit

Technological solutions for obtaining blocks with excavators, according to the thickness and dip of the deposit (beds)

Exploitation of the deposit will begin at the stratigraphically youngest member and the topographically highest part of the package of beds so as to enable the gravitational separation of the blocks downwards, i.e. always towards the free sides of the bed package, [16], [17].

It is evident that the best effect will be achieved by the selective exploitation of each bed along the dip, so as to achieve the best utilization and at the same time the classification of stone according to its appearance. A selective approach will make it possible to obtain a uniform stone during processing and ultimately facilitate the work when choosing the type(s) of stone for installation. It is certainly necessary to avoid making horizontal benches for this type of deposit, [17].

Figure 3.2 shows a proposal for the development of mining works on a slightly inclined deposit with rock beds up to 80 cm thick, crisscrossed with fractures up to one meter apart of different orientations.

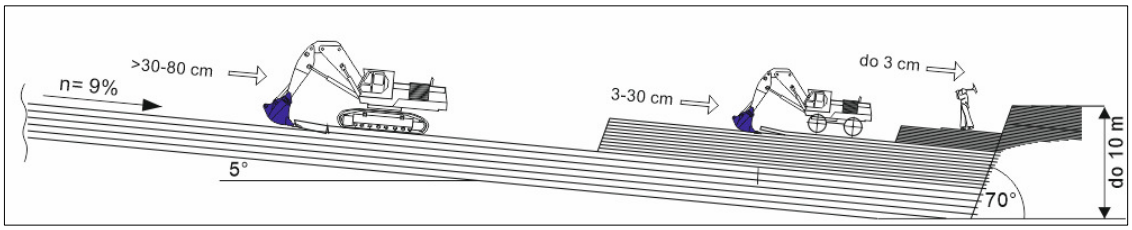


Figure 3.2 Development of mining works on a slightly inclined bed, with rock beds up to 80 cm thick

Exploitation is carried out with the development of mining works according to the strike and dip of beds. This technological solution specifies the use of excavators for breaking off thicker layers and manual excavation of thinner layers (up to 3 cm), [16], [17].

Technological solutions for obtaining blocks with hydraulic wedges and cutters, according to the thickness and dip of the deposit

In parts of the deposit with more compact layers, it will probably not be possible to break off the blocks using the force of a hydraulic excavator. Also, thickly bedded rocks may also appear in the deposit. Therefore, the technological solution shown in Figure 3.3 is proposed in such cases.

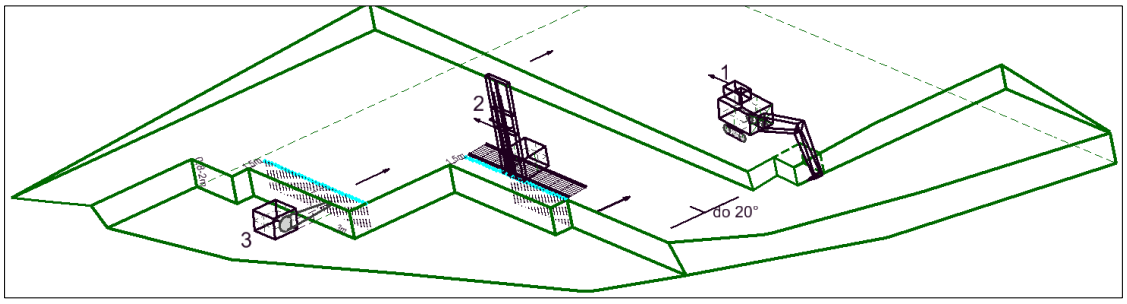


Figure 3.3 Proposal for obtaining blocks on inclined, medium and thick-bedded deposits, by a combination of hydraulic wedges and a chain cutter (1-excavator; 2-drill; 3-chain cutter)

Stone blocks are first separated with hydraulic wedges, according to the bed dip, and then cut with cutters according to the bed strike. In the process, bedding plane and joint systems, with which the rock is already discontinuous (separated) are used, so that blocks are obtained with as little energy consumption as possible, [2].

Exploitation of thickly bedded deposits (thickness up to about 200 cm) - case of Poljane

The "Poljane" deposit near Jajce contains medium to thickly bedded Lower Cretaceous limestones, light gray to dark gray in color (Figure 3.4). The thickness of the beds generally ranges from 80 cm to about 200 cm. The overall package of beds covers over a hundred meters. The strike of the deposit is Dinaric and the beds dip towards the northeast. The dip of the beds is from 15 to 25°, [2].

Figure 3.4 Location of DS beds at the "Poljane" deposit

At the "Poljane" open-pit mine, exploitation of dimension stone is carried out by developing horizontal benches along the strike and dip direction of the layers. Due to the oblique cuts in relation to the dip of the beds, there are difficulties with the selection or classification of the stone according to uniformity. Therefore, a technological solution that allows obtaining blocks by beds, that is, with a uniform appearance, is proposed (Figure 3.5).

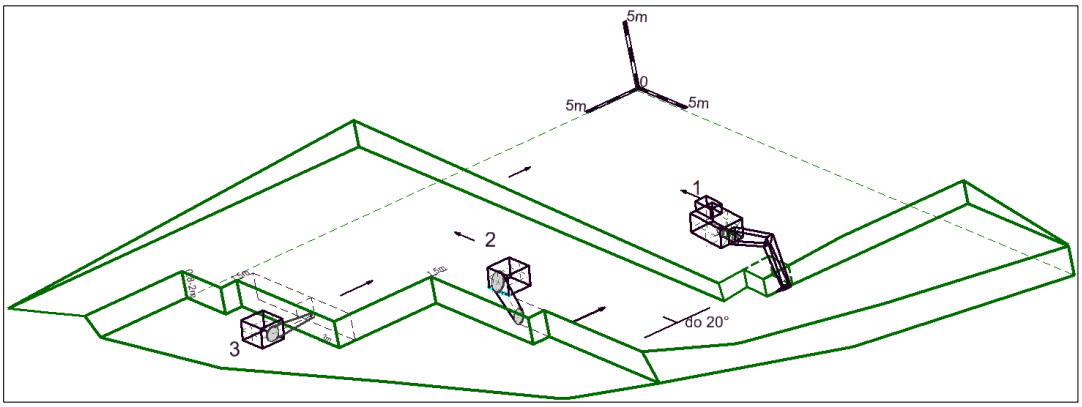


Figure 3.5 Proposal for extracting blocks on inclined, medium and thickly bedded deposits, using a combination of chain cutters (1-excavator; 2-chain cutter; 3-chain cutter)

According to Figure 3.5, the front of the mining works follows the strike of the beds while the direction of advancement coincides with the dip direction of the beds. At the same time, the benches are inclined parallel to the dip of the strata. In this solution, an excavator is used to remove the weathered upper layer of stone (along the dip of the beds). Stone blocks are first sawn with a cutter with a vertical cut according to the dip of the bed, and then with another cutter with a perpendicular cut according to the strike of the bed. The bedding plane and joint systems are also used in the process, for more economical production of blocks.

Exploitation of banked deposits

Exploitation of slightly inclined banked deposits - case of Brestovci

The DS deposit of "Brestovci" is located at the foot of the southwestern slopes of Dinara, at a distance of about 20 km from Knin. The deposit is composed of light brown to gray brown banked micritic limestones (d > 10 m), which stratigraphically belong to the oldest member of the Lower Cretaceous (K_1^1). The strike of the deposit is Dinaric and the beds dip towards the northeast. The dip of the beds is from 8 to 10°, [18].

The open-pit mine was opened more than 20 years ago, and the exploitation of the "Brestovci" DS deposit is already at an advanced stage. In cross-section, the dimension stone has a pronounced laminated structure. Due to the market demand, the deposit is exploited along prominent lamination planes, or bedding planes, where the faces of benches are parallel to the strike and perpendicular to the strike of layers (Figure 3.6).

Figure 3.6 Development of mining works on a gently inclined bed, along the dip of the beds

The technological process of exploitation of dimension stone at the "Brestovci" deposit is carried out with slightly inclined benches (up to 10°) with the combined use of a chain cutter and diamond wire saws. A cut parallel to the dip of the beds is made with a chain cutter (1), while a vertical cut along the strike of the beds (head) is made with one wire saw (2), and a vertical cut perpendicular to the strike of the beds, or in the dip direction, is formed with another wire saw (3) (Figure 3.7).

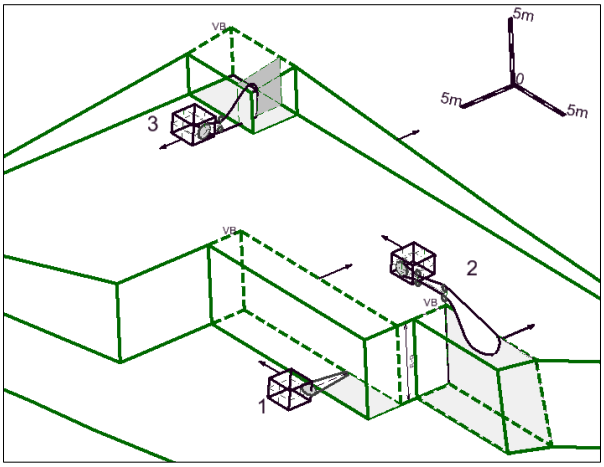


Figure 3.7 Plan for obtaining blocks on gently inclined thick-bedded, banked and massive deposits (d > 2 m), using a combination of a cutter and diamond wire saws
(1- chain cutter; 2- diamond wire saw-longitudinal vertical cut; 3- diamond wire saw-transverse vertical cut)

Blocks of a uniform appearance, which are sorted (selected) by the place of extraction, are formed with the described method. The blocks are marked so as to be easy to select and sort according to the uniformity of appearance during processing and installation of finished elements.

Exploitation of inclined banked deposits - case of Ljut

The dimension stone deposit "Ljut" is located on the northern side of the Pelješac peninsula, in the area of the municipality of Janjina. The deposit is composed of whitish, light gray to gray brown banked organogenic limestones (d > 10 m), which stratigraphically belong to the youngest members of the Upper Cretaceous (K_2^{3-6}). The strike of the deposit is Dinaric and the beds dip towards the northeast, [19]. The dips of the beds are variable and vary in a wide range of values, but the dominant dips are from 40 to 50°. In the deposit, there are certain structural elements, which are shown in a simplified form in Figure 3.8. Explorations established the presence of several types of rocks, of which three types that are closest to the ground surface (up to a depth of 100 m) are identified and are interesting for obtaining DS.

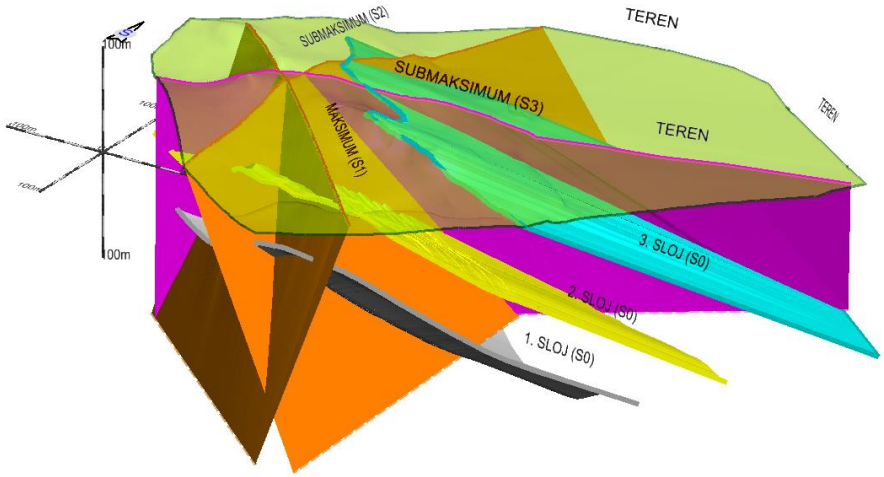


Figure 3.8 Spatial position of the primary discontinuities in the deposit "Ljut", [9]

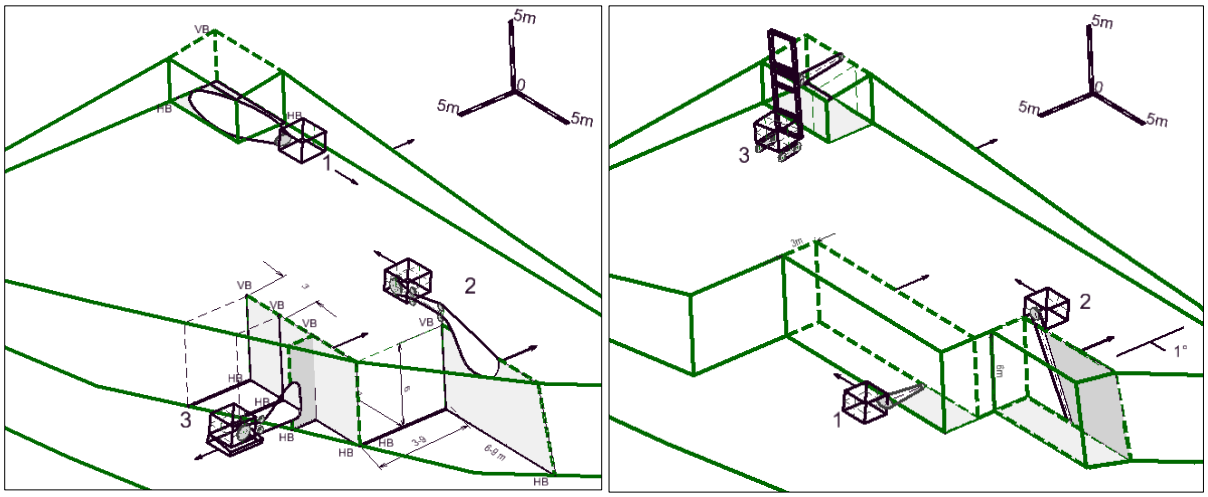
The spatial model shows the position of discontinuities (beds, maximum and submaximum of joint systems) that will have a great impact on the exploitability of the rock for obtaining DS, [8], [21]. In order to obtain the same (uniform) types of DS, it is necessary to plan the development of mining works along the strike and perpendicular to the strike of beds.

The development of mining works on steeper banked and massive deposits is similar to the described example for the "Brestovci" deposit. However, the important difference is that horizontal benches must be formed for steeper dips, which is understandable in the absence of more acceptable technological solutions.

The usual way of opening steep deposits on hilly (inclined) terrain is by making side cuts of a triangular shape using diamond wire saws, [14]. First, a horizontal cut is made (1), then a vertical cut is made along the strike (2) and finally a lateral vertical cut is carried out in the direction of the dip of the beds (3), as shown in Figure 3.9a.

Other technological solutions that increase the exploitation capacity and also facilitate the extraction of DS blocks are introduced after forming the horizontal planes-benches. Figure 3.15 shows the technological solution for obtaining blocks with chain cutters 3.9b.

Although the dip of the beds is unfavorable, selective exploitation with consistent monitoring of the strike and dip direction of the beds can be achieved with the described technological procedure.



a) opening the bench with wire saws b) bench development with cutters

Figure 3.9 Proposal for the opening and development of mining works on banked and massive deposits (1-horizontal cut; 2-vertical cut-head; 3-vertical cut-side)

3.2 Exploitation of the deposits of dimension stone with semi-regular and irregular shape (massive)

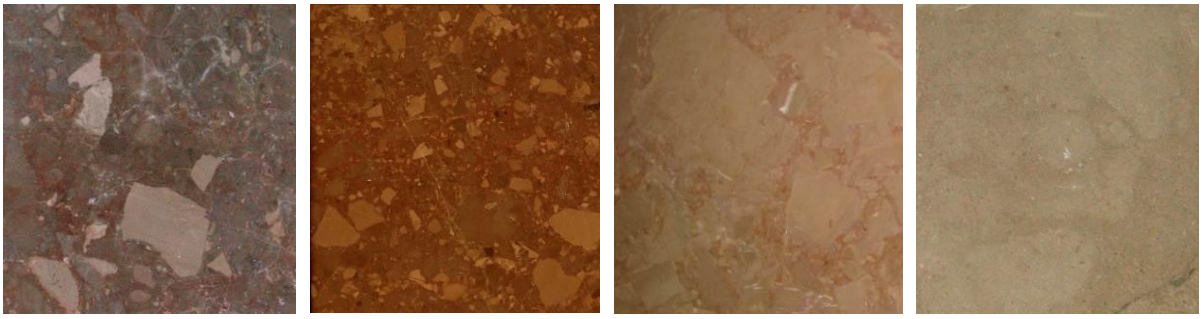
Exploitation of breccia deposits - case of Kusačko Brdo

Breccias and conglomerates were formed by the transformation of primary rocks. In the case of breccias and conglomerates, what usually occurred is the sedimentation of rock material, which was mechanically crushed and hydrodynamically transported to shorter (breccias, sharp edges of rock fragments) or longer (conglomerates, rounded rock fragments) distances from the place of formation of parent rocks, [6], [15]. In the transgression phase, the intergranular space was filled, and in the ground phase (regression) cementation or hardening of the breccia and conglomerate occurred, and deposits of semi-regular shape were formed, where most often the underlying stratum is of a regular shape and the overlying stratum is of an irregular shape, with possible changes both with depth and laterally. In the conditions where breccia and conglomerate deposits have remained complete, with less tectonic influence, and are found in zones of greater thickness (>10 m), they are interesting for DS exploitation. However, it is important to indicate that such deposits are more demanding for exploration and exploitation than deposits of stratified rocks, precisely because of the uneven spatial distribution and zonal structure. The carbonate breccia deposit "Kusačko Brdo" is analyzed below, where the interaction of mining works, processing and installation of DS is emphasized.

The DS deposit "Kusačko Brdo" is located in the locality of Ljubotići, at a distance of about 10 km northwest of Široki Brijeg. The deposit is composed of gray-brown, greenish, reddish to dark brown breccias that occur in the form of packages (four productive zones) of different thickness. The rocks from which the breccias were formed belong to the Albian-Cenomanian stratigraphic unit ($K_{1,2}$). The strike of the deposit is Dinaric, and the breccia packages dip towards the northeast, at an angle of 70 to 80°. The deposit was investigated in detail, with exploratory boreholes and trial exploitation, and a geological map was developed and the spatial position of the productive packages was determined.

Based on the data from the geological map and the interpretation of the cores of the exploratory boreholes, the structural elements and the differentiation of the breccia packages from the northeast to the southwest were determined.

It is indicative that all breccia packages differ in color and size of fragments, which is evident in Figure 3.10. A favorable circumstance is that the physical and mechanical properties of these breccias are quite uniform, that is, the variations of the test results are very small (< 10%).



type 1 type 2 type 3 type 4

Figure 3.10 Breccia types from the DS deposit "Kusačko Brdo"

The open-pit mine "Kusačko Brdo" was opened more than 20 years ago, and the exploitation of DS is already well advanced. Dimension stone (all types) is exploited in zones, where the fronts of the benches are parallel to the strike and perpendicular to the strike of the package (Figure 3.11).

Figure 3.11 Development of mining works at the "Kusačko Brdo" deposit, longitudinally and transversely to the strike

The technological process of obtaining DS blocks is performed according to Figure 3.7, or by a combination of a cutter and diamond wire saws.

Exploitation of massive (irregular) deposits - case of "San"

Carbonate rocks, limestones and dolomites, can be found, in addition to regular bedded forms, in semi-regular and/or completely irregular forms or deposits. As a result of mechanical and chemical (diagenetic) processes, limestone rocks can change from their original stratified forms to dolomite rocks, usually with irregular (massive) shapes and spatial distribution, [4]. Rocks crystallize as a result of the effects of temperature and pressure. As limestone is transformed into dolomite during diagenetic processes, calcium and magnesium and the crystal lattice are replaced, which is called dolomitization of the rock. However, the degree of

dolomitization of limestone rock can be different, both chemically and spatially. For this reason, limestone rocks that are partially dolomitized are classified as dolomitic limestones, while rocks with a dominant magnesium content, or a high degree of dolomitization, are classified as dolomites. A typical example of a dolomite deposit in which DS is exploited is the "San" deposit, which is analyzed below.

The DS deposit "San" is located in the locality of Crne Lokve, at a distance of about 20 km northwest of Široki Brijeg. The deposit is composed of saccharoid dolomite, which occurs in several varieties (Figure 3.12). Stratigraphically, the rocks from which the DS "San" deposit was formed belong to the Turonian stratigraphic unit (K_2^2). The strike of the deposits is Dinaric, and the dolomite packages dip towards the northeast, [1], [4]. The deposit was investigated in detail, with exploratory boreholes and trial exploitation, and a geological map was developed and the spatial position of the productive packages was determined.

The types of "San" stone are very similar in color and structure, and differentiation can only be made by performing mining works, that is, by cutting the stone. Therefore, trial exploitation played an important role in determining the distribution zones of individual types of dimension stone "San".

type 1 type 2 type 3 type 4

Figure 3.12 Types of DS from the "San" deposit

The maximum utilization of the rock mass and the selective exploitation of different types of stone will be achieved by the development of mining works according to:

- the strike and dip direction of the stone types (generally deposits)
- spatial pattern of discontinuities (dominant joint systems and faults).

Figure 3.13 shows the current development of mining works at the "San" deposit, where the positions of extraction of individual types of DS are indicated. DS types: 1, 2 and 3 are found in the structure of the deposit, i.e., they can be followed positionally by strike and dip direction. DS type 4 is not continuous but occurs in some places, in zones of water action at the contacts of discontinuity surfaces where the parent rock has acquired a yellowish or pink color, probably due to the introduction of the limonite component in the infilling of joints and fault surfaces (paraclases) and absorption through the effective porosity of rock.

Figure 3.13 Development of mining works at the "San" deposit, longitudinally and transversely to the strike

The technological process of obtaining blocks of DS "San" is performed, depending on the geometric shape of the bench, in two ways, specifically:

- with diamond wire saws, as shown in Figure 3.9a
- with a combination of a cutter and diamond wire saws, as shown in Figure 3.7.

The cutting tools used for extracting DS blocks must be adjusted according to the type of rock that is exploited and subsequently also processed.

4. RESULTS OF DIMENSION STONE INSTALLATION ACCORDING TO APPEARANCE UNIFORMITY

According to the spatial arrangement, or the position inside or outside the building, stone cladding is placed on vertical, horizontal and inclined surfaces.

The stone blocks are extracted from the deposit, and processed into final elements, with given dimensions and type of processing, according to the request of architects, or the place of installation.

The type of stone, method of processing and dimensioning of the final elements are determined by the architect in cooperation with the client according to the place (position) of installation. According to the given specification, the stone is processed from the selected blocks, in the stone cutting workshop and/or at the quarry. In the processing phase, it is very important to define how to cut the blocks with regard to the stratification or structure of the stone. Blocks can be cut in the following way:

- by bedding ("boards")
- transversely to bedding
- diagonally (obliquely) to bedding

How the blocks will be cut, considering the structure of the rock, will depend on the architectural solution for the spatial arrangement.

The final appearance of the space depends on the method of laying-placing the stone elements, which can be:

- with a uniform pattern (the structure and orientation of the stone elements are followed)
- with an uneven pattern (different orientation of stone elements)

The method of installation of several significant types of DS from the Dinaric area, which were described in the previous chapter, are presented in the following. Emphasis is placed on the geometric forms of DS elements for laying in interiors and exteriors, and the ways of laying according to the uniformity of appearance. The interdependence of final products (stone

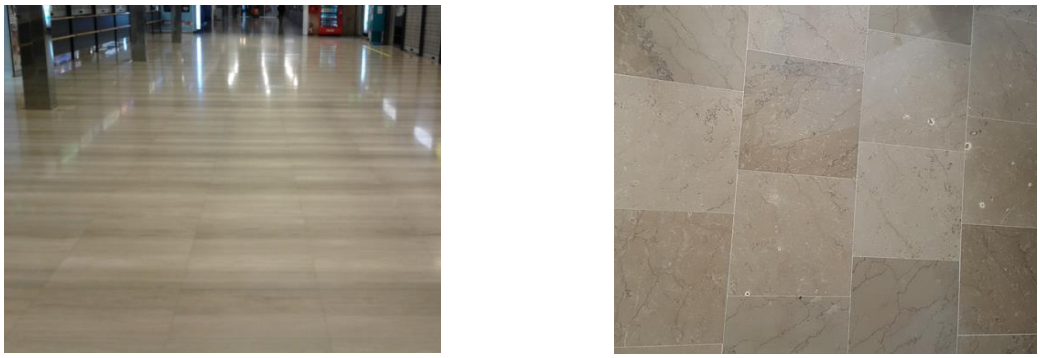
elements), methods of processing and extraction of DS blocks is indicated in the process, in terms of both appearance and the utilization of stone. Constructive installation elements (concrete base, adhesives, anchors, etc.) are a separate topic that is specific to the construction profession and is not considered in this paper.

Installation of DS in interiors

Internal spaces (interiors) are most often decorated using finely dressed stone claddings, such as: polished, brushed and ground plates, where the color and structure of the stone more or less becomes prominent (graininess, layering, fossil remains, sorting of materials, etc.). However, sometimes according to the architectural solution, finely processed stone cladding is combined with rough dressing such as: sandblasted and hammer chiseled (self-faced) elements.

For interior decoration, installation of stone elements with a uniform layout of the same or several types of stone is usually requested (Figure 3.14).

Figure 3.14a shows spaces with a large area of horizontal cladding (>1000 m^2). The aesthetic value is achieved by the unique ambient appearance, or the composition of uniform, geometrically placed stone plates. The distinctive layered structure indicates the way the stone blocks were cut, which points to the need to monitor the DS extraction method before and during the stone installation process.



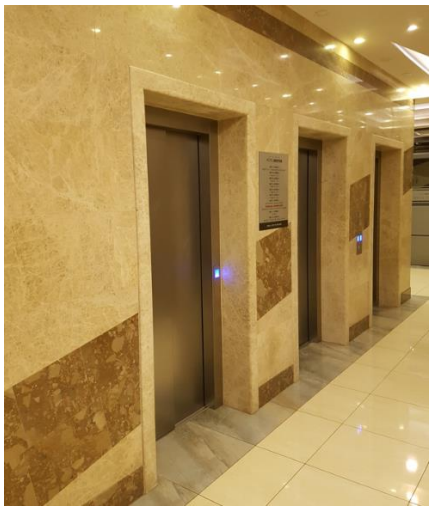
a) uniform layout b) varied layout

Figure 3.14 Cladding of horizontal surfaces in interiors

Cladding horizontal surfaces with plates without a pronounced layered structure (Figure 14b), provides a certain degree of freedom when placing the stone, but the aesthetic impression of uniformity of the stone plates is lost (Figure 3.14b).

When cladding vertical surfaces, different aesthetic impression can also be achieved by placing the same type of stone or by combining different types of stone (Figure 3.15).

cladding with a single type of stone

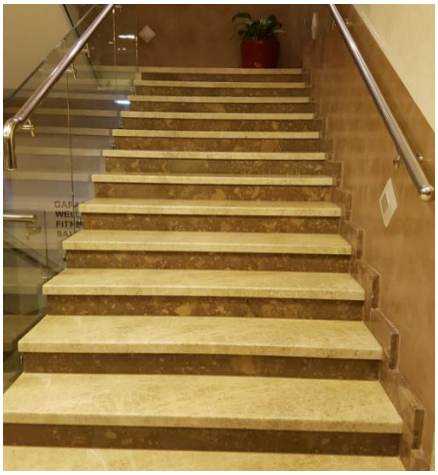


cladding with two types of stone

Figure 3.15 Cladding of vertical surfaces

The installation of stone on internal staircases requires high precision but also attention if it is desired to achieve ambient harmony. Regardless of which type of stone will be used for cladding, it is necessary to strictly observe the sequence of installation of stone elements (treads and risers), which is achieved by cutting blocks of the same type and numbering the installation positions. Decorativeness can be achieved by uniform transitions of the same type of stone or by a combination of two types of stone (Figure 3.16).

cladding with a single type of stone



cladding with two types of stone

Figure 3.16 Cladding of internal staircases

Installation of DS in exteriors

Claddings with different treatments and various types of stone can be used for exterior decoration, which opens up the possibility of better utilization of stone than in interiors. It is important to know that the primary structure of the cut plate is lost with rough dressing, so that the effect of a better uniformity of the appearance of stone is achieved.

There are several types of rough (rustic) dressing of stone, primarily for decorating exteriors (facades, staircases and yards), among which the following are the most commonly used: bush hammered, brushed, picked and self-faced (hammer chiseled) claddings.

Vertical claddings of buildings are most often made with picked, bush hammered or hammer chiseled (*bunja*) dressing (Figure 3.17).

hammer-chiseled cladding of the facade

picked dressing of the facade

Figure 3.17 Cladding of facades

Horizontal claddings of terraces, entrances and approaches (pathways) are made with ground, bush hammered, brushed or combined treatment, in the same or different dimensions. A very effective treatment for decorating yards and pathways is the so-called "tumble" processing where maximum utilization of stone of different types and dimensions is achieved (Figure 3.18).

Staircases are decorated with ground, bush hammered, brushed or combined treatment, depending on the exposure of the installation position to external effects (rainfall and frost).

bush hammered treatment-terrace

brushed treatment-entry

cut and tumble treatment-approach

Figure 3.18 Cladding of terraces, entrances and approaches to the building

The claddings of yard walls are treated with picked, bush hammered, hammer chiseled (*bunja*), cut or combined treatment of various types of stones of regular or irregular geometric shapes of different dimensions (Figure 3.19). A wide range of various types of stone, as well as treatment, shapes and dimensions provides the possibility of great utilization of the rock mass in the quarry. Blocks of lower categories and even smaller pieces of rock that are unusable for production of large-format plates can be used for cladding the yard walls.

different types and treatments | *bunja* treatment | *bunja* and picked treatment | picked t., irregular shape

Figure 3.19 Wall cladding

Installation of dimension stone in massive elements

Massive elements from dimension stone have aesthetic as well as functional value. Massive elements are processed like other elements in interiors and exteriors, according to specific requirements. Stone tables, fireplace claddings and benches in parks and squares (Figure 3.20) have already become common elements of construction in Herzegovina.

benches | table | fireplace

Figure 3.20 Massive elements

In terms of construction quantities, massive elements have a smaller share than cladding in interiors and exteriors, but they play an important role in the culture of living. In addition to business and residential buildings, many sacred buildings and monuments made of native Herzegovinian stone have become part of the cultural heritage that needs to be nurtured and developed.

5. CONCLUSION

The installation of dimension stone is the final part of the building construction process, where aesthetic value, in addition to functionality, plays a very important role. In terms of ambience, the space enriched with dimension stone represents the realized client's and builder's vision that has been translated from architectural solutions into reality.

The quality of dimension stone depends on the mineralogical-petrographic, physical-mechanical, chemical and aesthetic properties (characteristics) of the parent rock. Most projects require uniformity of quality and appearance of dimension stone, which is possibly achieved by selective exploitation of blocks. Therefore, it is necessary to plan selective extraction of dimension stone blocks, according to the condition of uniformity of quality and appearance. However, due to the conditions in the deposit, it is also necessary to optimize the development of mining works for maximum utilization of the rock mass.

By analyzing several typical examples from the Dinaric area, a division was made according to: type of formation, shape, strike, dip direction, dip and thickness of the dimension

stone deposit. According to the presented and discussed examples, it can be concluded that each deposit is specific and that there can be several types of dimension stone within one deposit. Therefore, a proposal is generally given for the development of mining works and technological solutions according to: deposit strike, dip direction of beds and discontinuities (strata and dominant joints).

The result of optimized exploitation will enable clients and architects to make an easier selection of stone according to uniformity of appearance and other properties.

Blocks of dimension stone are cut according to the architectural design for space decoration: by stratification; transversely to stratification; diagonally (obliquely) to stratification.

The final shape and dimensions, as well as the type of stone processing, are determined according to the ambient requirements or the place of installation. Emphasis is placed on the geometric shapes of dimension stone elements for laying in interiors and exteriors, and massive elements according to the uniformity of appearance.

Interior decoration is usually made with finely treated stone claddings such as: polished, brushed and ground plates, with a distinct color and structure of the stone (graininess, layering, fossil remains, sorting of materials, etc.). Sometimes finely dressed stone cladding is combined with rough dressing such as: sandblasted and hammer chiseled (self-faced) elements. In interiors, stone elements with a uniform layout of the same or several types of stone are usually installed.

For exterior decoration, claddings with different treatments and different types of stone are used, which results in a better utilization of stone compared to interiors. The primary structure of the cut plate is lost with rough dressing, and the effect of a better uniformity of the appearance of stone is achieved. Exteriors (facades, staircases and yards) are usually decorated using: bush hammered, brushed, picked and self-faced (hammer chiseled) claddings.

Massive elements have aesthetic and functional value and are processed like other elements in interiors and exteriors. The massive elements, made of native Herzegovinian stone, have become part of the cultural heritage that needs to be nurtured and developed.

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