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Standard Guide for Selection of Dimension Stone for Exterior Use[1]

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INTRODUCTION

Natural stone, while being perhaps the oldest building material known to man, can also be one of the most difficult of all building materials to properly evaluate, select, and specify. Every natural stone product is unique, having its own physical properties and performance capabilities. Responsible stone selection involves extensive and objective evaluation of both the stone material and the application in which it is required to perform.

This guide presents a cursory review of the different stone types commonly used in construction, common applications, available finishes, and factors affecting product costs. It is intended to be used in combination with good judgment, responsible engineering analysis, local building codes, and any other available resources. It is not a "how-to" or a "step-by-step" guide, and has been prepared with the assumption that the user has some familiarity in the use of natural stone prior to utilizing this guide.

Past performance is the best test of a dimension stone's durability. Yet because the physical properties of a natural stone can vary within a single deposit, even stones with a history of satisfactory performance may need to be tested to ascertain the quality of the current production stock. Common physical property tests include absorption, density, compressive strength, modulus of rupture, flexural strength, abrasion resistance, and anchor strength. Additional tests may also be required depending on the material and application.

In a high proportion of the cases, failure of a natural stone in service is a result of improper application, rather than the inherent properties of the stone. Placing stones in unsuitable environments, faulty fabrication, installation, or construction practices, and incompatible associated materials are frequent causes of stone system failures (for example, high-porosity stones in subgrade applications, inadequate anchorage or expansion space, mortars leaching alkalis, inappropriate strength mortars, staining grouts, voids in setting beds, and pavement stones with inadequate resistance to abrasion).

In selection of natural dimension stone products, the application as well as the aesthetic appeal must be considered. While aesthetics are important to the design, the selection of the proper stone material, thickness, anchorage, and related components is necessary to ensure meeting the performance and durability requirements of the design.

1. Scope

1.1 This guide is intended to be used by architects, engineers, specifiers, contractors, and material suppliers who design, select, specify, install, purchase, fabricate, or supply natural stone products for construction applications.

1.2 *Consensus Standard*—This guide is an industry consensus standard drafted in a cooperative effort among engineers, architects, geologists, producers, and installers of natural stone.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 97 Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone

C 99 Test Method for Modulus of Rupture of Dimension Stone

C 119 Terminology Relating to Dimension Stone

C 120 Test Methods of Flexure Testing of Slate (Breaking

[1] This guide is under the jurisdiction of ASTM Committee C18 on Dimension Stone and is the direct responsibility of Subcommittee C18.08 on Selection of Exterior Dimension Stone.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Load, Modulus of Rupture, Modulus of Elasticity)
C 121 Test Method for Water Absorption of Slate
C 170 Test Method for Compressive Strength of Dimension Stone
C 217 Test Method for Weather Resistance of Slate
C 241 Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic
C 503 Specification for Marble Dimension Stone
C 568 Specification for Limestone Dimension Stone
C 615 Specification for Granite Dimension Stone
C 880 Test Method for Flexural Strength of Dimension Stone
C 1201 Test Method for Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure Difference
C 1242 Guide for Selection, Design, and Installation of Dimension Stone Anchoring Systems
C 1352 Test Method for Flexural Modulus of Elasticity of Dimension Stone
C 1353 Test Method Using the Taber Abraser for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic
C 1354 Test Method for Strength of Individual Stone Anchorages in Dimension Stone

2.2 Provisions of dimension stone handbooks, manuals, and specifications should be reviewed for compatibility with the principles outlined in this guide.

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology C 119.

4. Significance and Use

4.1 *Related Components*—Natural stone is only one component of a building's construction. All related materials and assemblies need to be evaluated to ensure compatible interactive behavior with the stone product.

4.2 *Applicable Codes*—Every stone application shall comply with applicable building codes.

EXTERIOR APPLICATIONS OF DIMENSION STONES

5. Introduction

5.1 Natural stones have long been used and admired for their beauty and permanence. As a natural material, each piece of stone has features and physical characteristics that make it unique. The rich variation in color and texture, as well as its ability to age gracefully in the exterior environment, has made stone one of the most popular materials for construction, sculpture, and monuments.

5.2 Varieties of stone possess certain properties making it suitable for a specific application. Stone geology (mineral content and structure), compressive strength, flexural strength, resistance to absorption and erosion, as well as its ability to be worked, vary widely by stone type. These are all key characteristics that dictate the best use of the material and must be considered during the process of stone selection.

6. Exterior Applications

6.1 This guide is limited to the discussion of exterior applications of stone. Of these, there are several major categories, which are introduced briefly as follows:

7. Load-Bearing Masonry

7.1 Load-bearing masonry is perhaps the oldest form of stone construction. Its defining feature is the transferring of structural load vertically by relying on the compressive strength of the stone to support itself and other imposed loads. Due to the weight of the stone itself, structures built in this manner tend to be of limited height. As the height of the structure increases, the wall thickness at the structure's base must increase, thus requiring large individual stones, or multiple wythes of stone. The costs of such walls are typically higher than other systems, due to the large amount of stone and labor involved.

8. Cladding

8.1 In response to the limitations and expense of load-bearing masonry, stone cladding systems were developed. Cladding systems can offer the appearance of load-bearing masonry but without the mass and expense. Cladding systems also offer a wide variety of applications, allowing greater architectural innovation.

8.2 When stone is used as cladding, it is exposed to unique loading characteristics that can require complex structural analysis and detailing in order to be used successfully. Materials other than stone are also often integrated into cladding systems, requiring consideration of their material properties as well as compatibility with the stone components.

9. Building Trim

9.1 Stone has been and continues to be used in architecture to accent other building materials, or to perform a specific purpose. Stone is often integrated into wall systems as decorative belt courses, window sills, lintels, arches, or water tables. Stone can add an element of interest to buildings, in addition to performing as a durable wall component with a specific and well-defined purpose.

10. Pavements

10.1 From cobblestone streets to modern plazas, stone is used to carry vehicle and pedestrian traffic. Modern systems include those bearing on pedestals and traditional sand or cement-based setting bed systems.

10.2 Materials used for steps must have a high resistance to abrasion and provide a surface with adequate slip resistance for public safety. Many varieties of dimension stones, with appropriate finish, will satisfy both of these requirements.

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11.2 Steps are manufactured from dimension stones as "cubic," in which the tread and riser faces are of one piece of stone, and also "veneered" in which multiple pieces of thin stone material are placed over a concrete or steel frame to form the tread and riser surfaces.

12. Coping

12.1 Wall systems that are fully exposed to the environment, such as roof parapet walls, balcony and terrace enclosure walls, and planter walls, are particularly susceptible to water penetration. Stone coping and wall caps are often used to help protect the underlying wall system from excessive moisture penetration and associated distress.

12.2 Copings and wall caps can also add a visual accent to the wall system, improving the appearance of the wall system by defining changes in the wall configuration.

12.3 Stone copings and wall caps are typically jointed, therefore, protection of the wall system is also reliant on proper treatment of the joints.

13. Roofing

13.1 Roofing applications for natural stone are typically limited to slate, a variety of stone that can be quarried and fabricated into thin, shingle-shaped elements. Dense, nonporous stones can provide a durable, water-resistant roof system that effectively utilizes the unique physical characteristics of the material.

14. Ornamental, Sculpture, and Monumental Elements

14.1 Many varieties of stone possess characteristics that make them a desirable material for sculpting and carving. Most stone varieties can be worked by hand or power tools into unique shapes and representations, including engravings and reliefs. Properly selected stones can demonstrate resistance to environmental effects, thereby providing a sense of permanence to monuments and decorative sculpted items.

COMMON DIMENSION STONE TYPES—GRANITE

15. Mineralogy, Appearance, and Texture

15.1 The term "granite" has both geological and commercial definitions. There are many rock types that are not classified as granites by true geological definition, yet they are included in the commercial classification of granite because they exhibit similar performance and behavioral characteristics as true granites. For the purpose of this guide, "granite" is used in its commercial sense. This includes any visibly granular, igneous rock consisting mostly of feldspars and quartz accompanied by one or more dark minerals.

15.2 Typically, feldspar is the most abundant mineral found in granites, and because of this, the color of the granite is largely governed by the color of this mineral. The color can be modified by the quartz, hornblende, mica or any other mineral present in significant quantity. Dark granular igneous rocks, classified petrographically as anorthosite, basalt, diabase, diorite, or gabbro, are often referred to as "black granites." Using the rather broad commercial definition of granite, granites are available in a wide array of colors including pink, gray, white, red, black, brown, buff, green, and blue.

15.3 The majority of granites found in the industry are granular or crystalline in appearance, with the grain size varying anywhere between 2 or 3 mm up to 25 mm or larger. Some of the materials included in this definition will show a layered or plate-like structure due to recrystallization, folding, or other changes while the rock was in a plastic or semi-molten state. Such metamorphic rocks are called granite gneisses.

15.4 A granite with uniform distribution of the minerals is desirable for the supply of a large application with minimal color variation. Many commercial deposits exhibit remarkable homogeneity across vertical and lateral distances, while other deposits will display considerable variation between adjacent blocks or even within one block.

15.5 Many granites are "anisotropic," or "directionally specific" in either appearance or performance, and as such, dictate attention to the direction that they are quarried and sawn to achieve the desired visual and performance requirements. Other granites are nearly "isotropic," with similar appearance and performance characteristics regardless of the direction the material is cut.

16. Suitability for Use

16.1 Granite materials have one of the widest ranges of applications of any natural stone type. Architectural use of granite includes exterior and interior cladding, exterior and interior paving, furniture tops, and landscape applications such as curbs, retaining walls, or copings. Granite is frequently used in monument or memorial applications where permanence and weather resistance are primary considerations. The chemical resistance and dimensional stability of granite allow limited industrial applications such as pickling tanks, surface plates, precision machine bases, and paper machine press-rolls.

16.2 The particular finish specified for the granite may have a greater bearing on its suitability for use than the granite itself. Polished and honed finishes are popular for vertical surfaces because of their refined appearance and low maintenance requirements. These finishes are not recommended for walking surfaces as they have relatively poor slip resistance. Textured surfaces such as thermal, tooled, or sanded are commonly used in pedestrian traffic areas due to their favorable frictional properties.

16.3 *Physical Strength*—Physical strength properties of granite are determined by laboratory testing in accordance with ASTM standard test procedures for each physical property to be evaluated. Minimum or maximum values for each physical property, to aid in determination of a specific granite's suitability for exterior exposure, are in accordance with Specification C 615.

17. Standard Thicknesses

17.1 Most granite products are custom made to the designer's specifications. The slab thickness however, is best kept to the dimensional standards of the industry to benefit both delivery and economy. Standard nominal thicknesses of granite offered by major fabricators are listed as follows:

10 mm (3⁄8 in.) This is primarily a "thinset" floor tile thickness, and is limited to interior applications only.

20 mm (3⁄4 in.) The 20-mm (3⁄4-in.) thickness is very common for interior cladding, interior flooring, or furniture applications. Exterior use of this thickness is not recommended.

30/32 mm (1¼ in.)	The 30-mm (1¼-in.) thickness is generally considered to be the minimum thickness suitable for exterior applications, although specific design criteria may dictate the use of thicker material.
40 mm (1⅝ in.)	The most typical usage of this thickness is exterior cladding panels when design loads marginally exceed the capacity of 30-mm (1¼-in.) material.
50 mm (2 in.)	Predominantly an exterior cladding material, 50-mm (2-in.) panels are used when necessitated by high design loads or large panel sizes. The machining of decorative reveals in the granite panel may also require that this thickness be used.
80 mm (3 in.)	Occasionally used in exterior cladding applications when extremely large panels are required or when deep recesses are cut into the stone. This thickness is also common in pavement applications that are subjected to vehicular traffic.
100 mm (4 in.), 150 mm (6 in.), and 200 mm (8 in.)	These thicknesses are generally found in landscape and site applications such as curbs, coping, steps, or fountains. Granite of these thicknesses or thicker is usually referred to as "cubic" material.

18. Availability

18.1 Granites are found throughout the world, and most are known by a unique trade name in the industry. In many cases, a particular granite will be given additional trade names by different fabricators or brokers. There are extreme examples of stone types that are known by a half dozen or more names in the industry, therefore, the trade name alone may not adequately identify the selected material. Including the origin (quarry location) and quarry operator of the material in the specification will help to minimize confusion.

18.2 For major projects, there is usually insufficient inventory of block material available at any one fabricator's facility to supply the project. Supply of raw block material from the quarry to the fabricator will occur concurrently with fabrication throughout the duration of the project construction. The production capacity of the quarry must be carefully considered to ensure uninterrupted delivery of material to the fabricator at the required rate. This is further complicated when the source of the granite is distant from the fabrication facility.

18.3 The size of blocks obtainable from a granite quarry is unique to the specific quarry. Natural fissures and fracture planes existing in the rock formation will dictate the available block size and block shape. Some granite materials have been supplied in monolithic forms approaching 15 m (ft) in length, while other granites will not be available in panels larger than 1 m^2. The supplier of the material must be consulted during design phases to ensure that the design requirements can be satisfied by the specified material.

18.4 Many granites are sold in varying "grades" or "selections." Oftentimes, terms such as "monumental," "structural," "architectural," "quarry-run," "select," "clear," or "variegated" are used with the tradename of the granite to further clarify the material specified.

COMMON DIMENSION STONE TYPES—MARBLE

19. Mineralogy, Appearance, and Texture

19.1 Geologically, marble is a metamorphic rock resulting from the recrystallization of limestone. Marble has both geological and commercial definitions. Geologically, the name marble is applied to rocks comprising crystallized grains of calcite (calcium carbonate) or dolomite (calcium magnesium carbonate), or both. Commercially, the name marble has come to be applied not only to rocks meeting the geological definition but also to rocks ranging from pure carbonate to those containing very little carbonate, yet having compositions and textures that permit them to be polished. The commercial marble group includes geologically true marbles; compact, dense limestones capable of being polished (limestone marbles); serpentine rocks (mostly or entirely hydrated magnesium silicate); and travertine (porous or cellularly layered, partly crystalline calcite).

19.2 Commercial marbles come in an almost unlimited palette of colors. They may be uniformly colored or a mixture of two or more colors. They may have bands or streaks in varying colors, called veining, contributing to any number of patterns. Geologic marbles of almost pure calcite or dolomite, or both, are white although trace minerals may contribute off-white background shadings and colorful veining. The color, veining, clouds, mottling, and shading in marbles are caused by substances included in minor amounts during formation. Iron oxides make the pink, yellows, browns, and reds. Most grays, blue-grays, and blacks are of carbonaceous origin. Greens are caused by micas, chlorites, and silicates.

20. Suitability for Use

20.1 Marble has been used architecturally for centuries. It is one of man's oldest building materials, as a dimension stone. Yet, not all marbles are suitable for use as exterior dimension stone.

20.2 Some of the basic considerations to be addressed in selecting a suitable marble for exterior use are as follows:

20.2.1 *Texture*—Texture is defined as that aspect of the physical appearance of a rock that is determined by size, shape, and mutual relations of the component grains or crystals. Texture plays a very important part in the physical strength and resistance to exterior exposures of marble. Marbles with a fine-grained, equigranular texture (grains of uniform size) tend to be less resistant to the effects of exterior exposure than those with a medium- to large-grained, inequigranular texture (grains of markedly varying sizes). The latter usually have an interlocking texture (grains with irregular boundaries, which interlock by mutual penetration).

20.2.2 *Physical Strength*—Physical strength properties of marble are determined by laboratory testing in accordance with ASTM standard test procedures for each physical property to be evaluated. Minimum or maximum values for each physical property, to aid in determination of a specific marble's suitability for exterior exposure, are in accordance with Specification C 503.

20.2.3 *Soundness*—Marbles have been classified into four soundness groups. The basis of this classification is simply the usual fabrication and handling practices involved in working with the material. Practical experience with each material has deemed such practices to be both necessary and acceptable. The classification has no bearing on the cost of the material. The four groups are listed as follows:

20.2.3.1 *Group A*—Sound marbles with uniform and favorable working qualities; containing no geological flaws or voids.

20.2.3.2 *Group B*—Marbles similar to in character to Group A marbles, but with less favorable working qualities; may have natural faults; a limited amount of waxing,[3] sticking,[4] and filling may be required.

20.2.3.3 *Group C*—Marbles with some variations in working qualities; geological flaws, voids, veins, and lines of separation are common. It is standard practice to repair these variations by waxing,[3] sticking,[4] filling, or cementing. Liners and other types of reinforcement are used when necessary.

20.2.3.4 *Group D*—Marbles similar to Group C marbles, but containing a larger proportion of natural faults, maximum variations of working qualities, and requiring more of the same methods of finishing and reinforcing. This group comprises many of the highly colored marbles prized for their decorative values.

20.2.3.5 *Hysteresis*—Most dimension stones return to their original volume after exposure to high or low temperatures. Some marbles exhibit a phenomenon known as "hysteresis," or a permanent volume change after exposure to thermal cycling. Hysteresis typically manifests itself as a bowing of the marble panels, often suggesting a pillowed effect. In addition to the bowing, the face of the panels will become more porous, making the surface more vulnerable to attack by corrosive agents and freeze/thaw deterioration. If a marble which is subject to hysteresis is selected, careful research is required to determine the minimum thickness required to prevent failure of the cladding system.

20.3 Marble is a suitable and durable material for exterior dimension stone when properly selected, designed, and installed. The ultimate test for any specific marble is its past historical performance on existing structures. Some marbles, particularly those included in the Group C and D classifications, are not suitable for exterior use.

21. Standard Thicknesses

21.1 The following are standard thicknesses:

10 mm (3⁄8 in.)	Tiles in various size modules for "thinset" application of interior flooring and walls. Also used in exterior panelized systems with appropriate setting materials (for example, epoxy type or silicone type).
12 mm (1⁄2 in.)	Tiles in larger modules and some specialty commercial applications mostly for flooring where heavier traffic is anticipated. Also used in exterior panelized systems with appropriate setting materials (for example, epoxy type or silicone type).
20 mm (3⁄4 in.)	A standard slab thickness for use on interior walls, flooring and countertop work as well as specialty furniture type applications. May only be used on a *limited basis* for exterior walls, ground level work.
22 mm (7⁄8 in.)	Minimum thickness for toilet and shower partitions with stiles a minimum of 1 1⁄4 in. thick.
30/32 mm (1 1⁄4 in.)	A standard slab thickness for use on countertop work and interior walls. May be used for interior stair treads, sills, and specialty work. Also as a minimum thickness for use on exterior walls (multistory construction) and exterior pavers.
38/40 mm (1 1⁄2-1 5⁄8 in.)	Used for exterior walls and pavers as well as specialty work (pilasters, trim, and molding interior or exterior).
50 mm (2 in.)	Used for exterior walls, pavers, and specialty work.
75 mm (3 in.), 100 mm (4 in.), 150 mm (6 in.), or greater	These thicknesses are referred to as "cubic," and are typically applied in monuments, sculptures, and decorative work.

22. Availability

22.1 Marbles suitable for exterior usage are readily available from quarries and production facilities in the United States and many other countries throughout the world. However, for very large projects requiring thousands of square feet of cladding surface, the ability of the quarry to produce such quantities in the required color selection or quality should be thoroughly investigated in advance.

COMMON DIMENSION STONE TYPES—LIMESTONE

23. Mineralogy, Appearance, and Texture

23.1 Limestone is a commercial rock term embracing both limestone and dolomite. It is a sedimentary rock composed principally of calcium carbonate (the mineral calcite) or the double carbonate of calcium and magnesium (the mineral dolomite), or a mixture of the two. Limestones, like all sedimentary rocks, contain impurities that affect their appearance and properties, and the amount, kind, and distribution of impurities affect the suitability of the rock for commercial use.

23.2 Limestones are found in hues of white, brown, gray, yellow, red, or black, but those used commercially are commonly in light earth tones of gray, buff, reddish or yellowish buff, or mixtures of these colors. The appearance of the stone is affected not only by color but also texture, which is the size, shape, and arrangement of component grains, skeletal minerals, and crystals; by stratification, which is composition, thickness, and arrangement of component beds; and by finish, which is brought about by milling or fabrication. Limestones range in texture from those so fine-grained as to lack visible particles through coarse in which individual fossil shells may be apparent. In general, surfaces of similar stone that are polished will be darker in appearance than those that are broken, cut, or sawed. The appearance of limestone may change over time with exposure to weather because of the oxidation of minerals and accumulation of organic matter.

24. Suitability for Use

24.1 Dimension limestones are subdivided into three categories by density in accordance with Specification C 568:

24.1.1 *Low Density Limestone*—Limestone having a density ranging from 1760 to 2160 kg/m^3(110 to 135 lb/ft^3)

24.1.2 *Medium Density Limestone*—Limestone having a density greater than 2160 but not greater than 2560 kg/m^3(135 to 160 lb/ft^3)

24.1.3 *High Density Limestone*—Limestone having a density greater than 2560 kg/m^3(160 lb/ft^3)

[3] Waxing refers to the practice of filling minor surface imperfections such as voids or sand holes with melted shellac, cabinetmaker's wax, or certain polyester compounds. It does not refer to the application of paste wax to make the surface shinier. Not all materials commonly used for the purpose of waxing are durable in exterior exposures. Use of inappropriate materials may lead to unreasonable maintenance requirements or even failure of the marble.

[4] Sticking describes the butt edge repair of a broken piece of marble. This repair must include dowels or other mechanical anchors in conjunction with exterior grade adhesive.

24.2 Limestone has been successfully used as a dimension stone in all climates of the earth. Because there is a variety of physical properties found within the limestone group, it should be noted that a single variety of limestone may not be suitable for all applications. Selection of a limestone for use as a pavement application, for example, would involve different performance criteria than that for statuary or cladding applications.

24.3 Being of sedimentary origin, most limestone varieties are "anisotropic," or directionally specific in their physical and visual properties. As such, these materials generally have a preferred "rift," or plane of easiest splitting, direction. Some limestones do not display a preferential direction in splitting, and are generally referred to as "freestones."

25. Standard Thicknesses

25.1 Most limestone products are custom made to the designer's specifications. Ultimately, consideration of specific design requirements in conjunction with the stone's physical properties will provide a basis upon which to designate material thickness. Since standard slab depth may vary from one producer to another, it is best to check with the producer to determine the appropriate thickness to specify. The following list of standard thicknesses is provided only as a general guideline. Limestone is available in any number of incremental thicknesses beyond those listed.

20 mm (¾ in.) and 22 mm (⅞ in.)	Minimum thickness for interior flooring and wall veneer applications, limited to high-density limestone. Panel size and design criteria may dictate the use of thicker material.
38 mm (1½ in.)	Typical thickness of high-density limestone for interior flooring and wall veneer.
50 mm (2 in.)	Minimum recommended thickness for all applications of low- and medium-density limestone, although some producers may be able to provide a lesser thickness depending on the application. The minimum recommended thickness for exterior applications of high-density limestone is 50 mm (2 in.). Panel size and design criteria may dictate the use of thicker material.
76 mm (3 in.)	Typical thickness for exterior applications.
100 mm (4 in.)	Used when necessitated by high design loads or large panel sizes. The machining of decorative reveals in the limestone panel may also require that this thickness be used. The nominal thickness of standard splitface stone veneer is 100 mm (4 in.), often used in conjunction with brick.

26. Availability

26.1 Through time, the nature of the quarrying industry has changed from many small, relatively inefficient quarries, to a few large, relatively efficient quarries. Limestone used in older buildings may no longer be quarried today, but stone with similar color and texture may be found to match those no longer being produced.

COMMON DIMENSION STONE TYPES—QUARTZ-BASED

27. Mineralogy, Appearance, and Texture

27.1 The term "quartz-based" is the commercial definition used to define rock that has high contents of quartz and silica. Sandstone and bluestone are two common terms used to designate rocks of this type. Sedimentary in origin, this rock generally contains a wide variety of trace minerals that oxidize to produce a broad spectrum of colors, both within the deposit and characteristic to specific deposits.

27.2 Quartz-based stone can be found in shades from light buff to dark blue-gray. Composition also varies widely from coarse, well-defined grains of quartz to very fine, tightly bonded particles, which appear almost homogeneous in structure. The texture of the finish is affected by the basic structure of the rock. The finer the grain size, the smoother the finish that can be attained.

27.3 As all quartz-based stones are sedimentary in origin, they have specific bedding planes and are therefore "anisotropic," or directionally specific in their properties to varying degrees. This can affect the appearance or performance of the stone, or both.

28. Suitability for Use

28.1 Quartz-based stones are disbursed widely throughout the world. Ease of fabrication, as well as the range of available colors has made this type of stone popular for centuries.

29. Standard Thicknesses

29.1 The standard thicknesses are as follows:

20 mm (¾ in.) to 50 mm (2 in.)	Generally, this is the minimum range of thicknesses that are considered suitable for exterior paving applications for pedestrian traffic.
50 mm (2 in.) to 80 mm (3 in.)	These thicknesses are most often found in exterior cladding applications with low design loads or small panel sizes, or both.
125 mm (5 in.), and 150 mm (6 in.)	These thicknesses are most commonly used in coping, water tables, and belt courses.
200 mm (8 in.) to 450 mm (18 in.)	This range of thicknesses is used on architectural, monumental, and split-face ashlar applications.
200 mm (8 in.) to 600 mm (24 in.)	Used in landscape applications, such as retaining walls, steps, and curbs. Stone of these thicknesses are frequently load-bearing, and often referred to as "cubic stock."

30. Availability

30.1 Quartz-based stones are found in many areas of the United States. Stones of specific physical characteristics are found in localized geographical areas. Consideration must be given to the design requirements as well as the color. Capability of the supplier is a very important consideration. The supplier should be consulted during design to ensure that the design requirements do not exceed the fabrication capability of the specific stone.

COMMON DIMENSION STONE TYPES—SLATE

31. Mineralogy, Appearance, and Texture

31.1 Slate is a microcrystalline, metamorphic rock commonly derived from shale. The shales from which slates originate were deposited previously as clay beds. Slates are composed mostly of micas, chlorite, and quartz.

31.2 Slates are largely "anisotropic" or "directionally specific" in their properties. The micaeous minerals have a subparallel orientation resulting in very pronounced cleavage planes within the rock. This property enables most slates to be split into thin, strong sheets.

31.3 Slates vary in color from the monochromatic tones of black and gray to green, red, blue, purple, yellow, brown, buff, and mottled varieties. Gray and blue slates are so colored due to the presence of carbonaceous material, while most other colors are due to the presence of iron compounds.

32. Suitability for Use

32.1 Slate is typically a very dense material displaying favorable resistance to abrasion and chemical attack. For centuries, the bulk of slate production has been used in roofing and pavement applications, where its service lives have been well-documented. Slate has been used successfully in all of the following applications: roofing; paving/flooring, and thresholds; exterior spandrel, cladding, curtainwall, and fascia; treads, risers, and stringers; countertops, vanities, laboratory tops; exterior window sills / interior window stools; hearths, mantels, fireplace surrounds; baseboard, wainscot, and miscellaneous trim; sanitary partitions; and blackboards.

32.2 One of the most important properties of a slate material is the permanence of color. Some slates maintain their original color for years, while others change color shades after relatively short exposures to weather. Such changes are often due to the presence of small quantities of iron-magnesia carbonates, which decompose readily and form a yellow hydrous iron oxide called “limonite.” Therefore, slates are of two types; “unfading” and “fading.” There is currently no reliable test method available to predetermine a slate’s susceptibility to fading. Evaluation of the material’s historical performance in existing exterior applications is used to predict the color permanence of slate.

33. Thickness

33.1 Unlike other dimension stone types, producers of slate tend to be less standardized in their fabrication methods and product offerings. Available dimensions and their economic impact are dependent upon the individual fabricator’s equipment and typical production practices.

33.2 Due to the nature of slate being a “layered” stone that is easily split to approximate thickness, most producers may supply thicknesses in 3-mm (1/8-in.) increments from 5 mm (3/16 in.) to 80 mm (3 in.). The following thicknesses and products are the most common supplied.

5 mm (3/16 in.)	Standard roofing slates
6 mm (1/4 in.)	“Thinset” floor tiles and wall tiles for interior residential use.
10 mm (3/8 in.)	“Thinset” floor tiles for interior residential use and some light duty commercial uses. This thickness is also common for blackboards and furniture top inserts.
13 mm (1/2 in.)	Flooring, baseboard, door thresholds, fireplace facings.
15 mm (5/8 in.)	Flooring, baseboard, window stools and furniture applications.
20 mm (3/4 in.)	Flooring, baseboard, backsplashes, hearths, mantels, vanity tops and interior panels, and cladding.
25 mm (1 in.)	Flooring, paving, window stools and sills, treads and risers, wall caps, cladding panels, hearths and mantels, countertops and vanity tops, and sanitary partitions. This is a common thickness for most slate products.
30/32 mm (1 1/4 in.)	Paving, “minimum” thickness recommended for exterior cladding applications. Many products supplied in 25-mm (1-in.) thickness are also supplied in this thickness for aesthetic purposes.
38 mm (1 1/2 in.)	Exterior spandrel, cladding, curtainwall, facia panels, soffit panels, treads, wall caps, and copings.
45 mm (1 3/4 in.)	Exterior spandrel, cladding, curtainwall, facia panels, soffit panels, treads, wall caps, and copings.
50 mm (2 in.)	Exterior spandrel, cladding, curtainwall, facia panels, soffit panels, treads, wall caps, and copings. Also a typical thickness for hearths.
57 mm (2 1/4 in.)	Exterior spandrel, cladding, curtainwall, facia panels, soffit panels, treads, wall caps, and copings.
63 mm (2 1/2 in.)	Exterior spandrel, cladding, curtainwall, facia panels, soffit panels, treads, wall caps, and copings.
70 mm (2 3/4 in.)	A common thickness available by most producers.
80 mm (3 in.)	Used mostly for slate cemetery markers. Also common for copings and wall caps.

34. Availability

34.1 Slate is available from quarries throughout the world. Domestically, the black slates are indigenous to Pennsylvania and Virginia, while the red, green, purple, and mottled slate colors are found in the New York-Vermont slate belt. For large projects it would be desirable to determine the dimensional capability, production, and historical performance of the slate to be specified.

BUDGET – COMPONENTS OF MATERIAL COST

35. Introduction

35.1 The total cost of an exterior stone installation is the sum of the costs of many different issues involved in designing, obtaining materials, and installing the system. An understanding of the primary cost issues is beneficial to developing cost-effective designs and developing accurate estimates of cost.

36. Testing

36.1 The extent of laboratory and field testing required for a specific project is controlled by many factors, including the type and variability of the stone material, the type of anchorage, method of installation, size and thickness of stone, size of project, and the available performance history of each of the components of the system.

36.2 The cost of a testing regimen can vary from zero to several hundred thousand dollars. On smaller projects, it is often more cost effective to over-design the system, rather than to engage in an extensive testing program in hopes of utilizing all components to their fullest capacity. For larger projects, or where the stone installation is more sensitive to variations in material, a testing regimen to more accurately define stone characteristics may provide an advantage.

37. Engineering

37.1 The engineering authority responsible for the stone design may also administer related services, such as quality assurance and quality control. Such services may include shop drawings, testing programs, and product/supplier observations. Product observations frequently include monitoring of fabrication tolerances and adherence to approved range mockups. Some of these services may be performed by the technical support provided by stone or anchorage suppliers.

37.2 Engineering should be provided by professionals who are experienced in stone facade design. While this cost may be a significant component of the total cost, a specialist can often provide superior design details and provide an economically reasonable long-term envelope design. Some suppliers provide technical assistance by internal design specialists. Economy may be gained by taking advantage of these resources.

38. Shop Drawings

38.1 A shop drawing is a highly detailed drawing that shows the net stone dimensions, joint dimensions, anchor locations and orientations, and relationship details with other building components. Because stone products are usually shop-fabricated, shop drawings are normally required on all stone projects. The cost of providing these construction documents is a relatively small, but often overlooked, cost of the cladding system.

38.2 Shop drawings are often provided by the fabricator of the material, but they may be provided by an independent party. When provided by an independent party, the supplier of this service must be familiar with the capabilities and limitations of both the product and the fabricator's machinery, and the stone fabricator should review the drawings prior to submittal to the entity responsible for final review.

39. Quarrying

39.1 The cost of extraction is highly variable amongst dimension stone types. The uniformity and continuity of the stone deposit affect yields, which are a primary factor in determining the unit cost of the material. Access to the quarry site, local labor availability, mineral rights royalties, and reclamation responsibilities are also factors in raw product costs.

39.2 Some stone materials are sourced from multiple quarries with multiple operators. Specification of these stones may require identification of the exact excavation, or portion of excavation, from which the stone is to be obtained.

39.3 The size of panels required for the project and the capability of the quarry to economically supply these sizes affect the costs. Understanding the standard sizes of slabs or blocks, and utilizing panels with the least waste in the slabs can be more economical. Some producers may offer pricing incentives for designs accommodating the standardized sizes that they produce most efficiently.

39.4 The costs of the blocks can change between the time when preliminary budgets are given and the time when delivery of stone is required, resulting in an unexpected change in the final price.

40. Transportation to the Fabricating Facility

40.1 Fabrication yields of stone products vary considerably between stone types and specifications of the finished products. Material not included in the primary product is typically reclaimed for use as a byproduct, although the byproducts often do not recover large amounts of revenue for the producer. The cost of transporting raw quarry blocks to the fabrication site then becomes significant, as it includes the freight cost of both the primary product and byproduct portions of the material.

40.2 This transport can be intercontinental, requiring both inland and marine transport of the material. Many stones quarried in one country can be fabricated in the same country. Blocks can also be distributed worldwide so that many countries and fabricators have access to the stone. Sufficient inventories of blocks may be available for purchase for some stone varieties, while others may require quarrying and fabrication activities to run concurrently.

41. Fabrication

41.1 Sawing slabs from the stone block is normally the first operation to be completed at the fabrication site, and is typically one of the largest factors in fabrication costs for dimension stone products.

41.2 Applying the face finish is typically done immediately after slabbing. Some materials require additional processing steps, such as resinating, netting, or gluing prior to being worked.

41.3 Cutting the slabs to the required finished building panel size is, in itself, a relatively low cost operation. It is at this step, however, that the yield of the material is determined. Establishing typical sizes or "modules" in the building design to maximize the use of the typical stone slab sizes for the selected material will increase yields and reduce costs.

41.4 Edge treatments, such as polished edges, chamfers, or rustications, are applied after the panel is cut to size. The cost of edge treatments varies greatly with the type of treatment specified as well as the equipment available to the fabricator. Modern machinery specifically tooled to complete a common task will do so very efficiently.

41.5 Preparing the stone panel to accommodate anchorage hardware can be done in the field during installation, but cost and quality control favor completion of this activity in the fabricator's facility. Researching the fabricator's standard profiles and locations for anchorage, and designing hardware to interface with these standards, will result in cost savings to the project.

41.6 The project may require specialty items, such as carving of text or graphics, profile cutting, or multiple finishes on one piece of stone, radially cut stone, shaped stone, panels in non-rectilinear format, or false joints. These items can significantly escalate costs.

41.7 Packaging, also referred to as "bundling" or "crating" of the finished material, is done by the fabricator. The sophistication, and therefore the cost, of the packaging can be affected by the mode of transport (that is.: truck, rail, marine), handling considerations at the project site, or anticipation of extended storage of the material.

41.8 Identification of custom fabricated pieces is normally done via alpha-numerical codes on shop drawings, with corresponding identifications on the stone pieces and packing lists. A lack of this type of tracking can impact costs due to misplaced or missing pieces.

41.9 Additional costs are incurred when panels need to be cut to fit at the jobsite or local shop. The cost of field or local labor may be higher than that at the original fabrication site, in addition to a loss of efficiency due to fabricating outside of a shop setting. Rehandling, transport, and possible loss due to breakage will impact the project cost.

41.10 A requirement for providing additional material or attic stock, in the form of panels or slabs, should be considered to accommodate post-construction damage to the stone from outside forces, breakage during installation, or shortages for unforeseen reasons. If applicable, the cost of attic stock must be allowed for in project estimates. The need for attic stock increases with distant stone sources and compressed project schedules.

42. Anchorage and Support Hardware

42.1 Anchorage hardware may be supplied by the fabricator, the installer, or a third party.

42.2 The supplier of the anchorage hardware usually offers standard configurations to accommodate common attachment requirements. Utilization of these standard hardware items will help reduce costs.

42.3 Some exterior stone is now being installed with adhesive attachment, thereby avoiding the complexities and costs of mechanical anchorage.

43. Transportation to the Project Site

43.1 The cost of transportation from the fabricator's facility to the project is generally governed by the distance between the two sites and the mode of transportation.

43.2 This transport can be intercontinental, requiring both inland and marine (land or ocean) transport of the material. On imported stone, freight costs are also affected by the type of container being used, the country of origin, and the shipping line. Freight costs can vary as well as the speed of delivery from port to port. The availability of containers for intercontinental freight should also be considered.

43.3 If the stone is imported, additional costs for brokerage fees, fumigation, duties and other fees may apply.

43.4 Pending the location and type of project, the stone product may be subject to local taxes.

43.5 Urgently needed items, such as approval samples, mockups, or replacement pieces may require transport by air, which is notably more costly than surface transport.

43.6 The contractor, architect, and owner's representatives may be required to visit the fabricator or quarry, or both. The cost of such travel should be considered in the initial estimate of the product cost.

43.7 Fabrication schedules and project site conditions may dictate the need for temporary off-site storage of the material, which will result in additional handling and cost.

44. Installation

44.1 Installation of the dimension stone entails too many variables to be adequately addressed within the scope of this document. The designer is advised to contact local installing contractors for estimates of installation costs based on previously completed, similar projects.

45. Joint Treatment

45.1 Caulking or pointing of stone joints is commonly included in the installation cost. On some projects, it may be contracted to another party.

46. Cleaning and Protection

46.1 Because other construction activity on the project site occurs after stone installation, the finished stone installation is normally required to be protected from damage by other trades and cleaned prior to acceptance by the owner.

46.2 Other considerations that affect cost include:

46.2.1 A requirement for providing additional material or attic stock, in the form of panels or slabs, should be considered to accommodate post-construction damage to the stone from outside forces, breakage during installation, or shortages for unforeseen reasons.

46.2.2 A repellent, anti-graffiti application, or other treatment may be required for some stonework. The type of treatment will be influenced by the stone type and finish, as well as the service environment.

46.2.3 When budgeting, some firms retain local cost accounting companies to estimate costs.

46.2.4 Having local installation companies review preliminary drawings and advise of estimated budgets for the stone installation, including consideration of the issues raised in this section, is advisable. Additional information regarding costs and budgets may also be available from trade associations and their members.

46.2.5 The time frame of the project need also be considered. The greater the time period between budget pricing and actual purchase, the greater chance for price escalations to occur between budgeting and purchasing.

46.2.6 For imported stone, the exchange rate of the importer's currency to the exporter's currency should also be considered, as this rate fluctuates daily.

47. Other Considerations

47.1 As all projects are unique, there may be costs associated with a particular project that are not discussed in this text.

FINISHES

48. Introduction

48.1 Available finishes will vary between producers. The finishes listed herein are the most commonly found finishes in the industry.

48.2 Many fabricators have marketed variations of standard finishes, often by modifying the finish with high water pressure jetting or abrasive brushes. Most often, these finishes will be proprietary finishes available from a single source. It is best to consult with the manufacturer before specifying a material/finish combination to ascertain its availability prior to specifying it.

48.3 Table 1 has been created to reference the applicability of the various finishes to the various stone material types.

TABLE 1 Applicability of Finishes for Various Stone Types

	Granite	Marble	Limestone	Quartz-Based	Slate
Polish	X	X	X[A]		
Hone	X	X	X	X	X
Thermal (flamed)	X[B]		X[C]	X	
Sanded (sand blasted)	X	X	X	X	
Bush-hammered	X	X	X	X	
Split	X	X	X	X	
Rock-face	X	X	X	X	
Smooth			X	X	
Sawn	X[D]		X	X	
Natural cleft	X[E]		X	X	X
Sand rubbed		X			X
Machine gaged			X		X
Natural strata	X		X	X	

[A] A polished finish is not achievable in all limestone varieties.
[B] There are some stones included in the granite group that are not capable of taking a thermal finish.
[C] In limestone, thermal finish applicability is generally limited to dolomitic limestone varieties.
[D] Sawn finishes in granites are typically treated with some type of additional enhancement, that is, water or sand blasting.
[E] Natural cleft is more commonly referred to as split finish in granites.

49. Finishes

49.1 A list of the most commonly available finishes is included in this section with the industry standard name.

49.1.1 *Polish*—A polished finish is a smooth, glossy and highly reflective finish produced by mechanical abrasion and buffing.

49.1.2 *Hone*—A honed finish is a smooth, nonreflective finish produced by varying degrees of mechanical abrasion.

49.1.3 *Thermal (or Flamed)*—This finish is produced in granite, granite-like, quartz-based, and dolomitic limestone materials by a brief exposure to a high temperature flame. The process results in an exfoliation of the surface, creating a textured finish.

49.1.4 *Sanded (or Sandblasted)*—Also referred to as "dusted," sanded finish is produced by "sand-blasting" the material with abrasive particles at high velocities. The resultant finish is a finely textured surface, which is generally lighter in appearance than the untreated stone. Visual characteristics such as color and veining are not as prominent through this finish.

49.1.5 *Bushhammer*—This finish is made with a pneumatic hammer and a carbide tipped head having numerous points. The resultant finish is a textured surface with a relief of up to several millimetres. The direction of the finish application may or may not be visible in the final product.

49.1.6 *6/8 Cut (or 6/8 Point)*—This finish is made with a pneumatic hammer and a carbide tipped chisel having 6 or 8 closely spaced straight blades. As the pneumatic hammer traverses that stone, the chisel is rotated 10 to 30° producing a "herringbone" effect.

49.1.7 *Split (or Splitface)*—Split finish refers to the natural cleft surface left when the rock is broken. The breaking of the stone is done with driven wedges. Material with split surfaces is usually supplied in low course heights and laid in a bonded pattern similar to brick masonry.

49.1.8 *Rockface (or Hand-Hewn, or Rock-Pitched, or Pitched)*—These terms describe a finish which is an embellishment to a split surface. The split surfaces are "hand-pitched" with carbide tipped chisels to produce a protruding or "pillowed" profile.

49.1.9 *Smooth (also referred to as "Machine Smooth," or "Diamond Ground")*—As its name suggests, it is a smooth surface with a minimum of surface interruption. This finish can be achieved by either sanding or grinding.

49.1.10 *Sawn*—Sawn finish is a general term describing a surface that has been chat, shot, sand, or diamond sawn. It is comparatively rougher than "honed" or "smooth."

49.1.11 *Natural Cleft*—The natural cleft surface is achieved by splitting the material along its natural cleavage plane. While available in some other stone types, natural cleft finishes are most commonly associated with slate.

49.1.12 *Sand Rubbed (or Abrasive)*—A nonreflective, matte finish with a slight grain or stipple pattern visible on the surface.

49.1.13 *Machine Gaged*—Machine gaged defines a surface that has been ground smooth with circular abrasive heads. The degree of smoothness may vary from one producer to another. Slight, circular patterned swirl marks may be visible in some material having this finish.

49.1.14 *Natural Strata (or Quarry Face)*—A rough, uneven finish, similar to splitface, but the surface of the stone is left as it naturally occurs at the top layer of the sedimentary formation, quarry seam, or bedding plane.

49.1.15 *Tooled*—A finish with a linear textural pattern, with concave parallel grooves usually 6, 4, or 3 mm on center (4, 6, or 8 grooves per inch).

EVALUATION OF PROPOSED APPLICATION ENVIRONMENT

50. Introduction

50.1 The decision to use dimension stone as a component in a building mandates that the designer evaluate the latter in terms of its effects upon the dimension stone product. The design of the building structure, related elements, and the dimension stone units may need to be altered to ensure satisfactory performance throughout the anticipated service life of the building.

51. Building Movements

51.1 Dimension stone units are rigid, brittle materials. As such, they do not accommodate dimensional changes very well within the individual stone unit. Modern building frames are constantly moving in reaction to the various loads imposed upon them. To accommodate movements in the building frame, "soft" joints are required between some or all of the dimension stone units. The size and frequency of these joints should be determined by the anticipated dimensional changes in the building frame, and the compression, extension, and shear capabilities of the material filling the soft joints.

52. Thermal Expansion

52.1 Differential heating and cooling of the variety of components in the building frame and skin create dimensional variations which must be accommodated in the stone system design. These movements are typically absorbed via the use of a "soft" joint, and the size and frequency of these joints is determined by the anticipated dimensional changes in the cladding as well as the compression, extension, and shear capabilities of the material filling the soft joints.

52.2 Variations in temperature within the stone units, particularly related to partial or full direct solar exposure, can give rise to temperature induced flexural stresses within the stone unit that may equal or exceed those related to wind loading. This should be considered in design for both panel thickness and anchor capacity.

53. Construction and Fabrication Tolerances

53.1 The attachment system of the dimension stone unit is required to have sufficient adjustment capabilities to accommodate the cumulative tolerances of the fabrication, field conditions, and erection of all components. It is not uncommon for this to exceed 25 mm (1 in.). The engineering authority for the system must analyze the system's ability to resist all anticipated loads at the extreme limits of its adjustment.

54. Wind Loading

54.1 As modern stone cladding units can be very large, wind loading is one of the principle forces to be resisted in the system design. Stresses arising from wind loading should be considered in design for both panel thickness and anchor capacity. For stone panels with complex geometry or intermediate anchors, deflections may need to be modeled to demonstrate actual loads at each anchor location during maximum wind load exposure.

54.2 Independent analysis of gravity loads and wind loads may not adequately address the effects of the two loads in combination. Due to the geometry of the anchorage assembly, wind loads can result in an increase or decrease of vertical loads on the anchor. It is usually a requirement to analyze the anchorage system with simultaneous gravity and positive/negative wind loads.

55. Seismic Loads

55.1 Seismic loads, particularly with thick stone panels, can exceed wind loads. Unlike wind loads, seismic loads can work both perpendicular to or parallel to the building face. Specialized anchors may be required to resist loads which are horizontal, but parallel to the building face, as this is a loading direction not found in non-seismic areas.

55.2 In addition to inertial loads, the inter-story drift of the building frame is a consideration in seismic design. Restraint anchors must have the capacity to adequately slip to accommodate parallelogram configurations of the building frame.

55.3 The use of "soft" joints will be required in seismic areas. Such joints must accommodate compression, extension, and shear movements within the joint filler.

56. Traffic Loads

56.1 Traffic loads, or any concentrated loads on a stone paver require extensive study. The heaviest anticipated load of each definable ″footprint″ must first be established. Then the effect upon the paver subjected to the load, including dynamic load, must be analyzed for every conceivable position and orientation of the load.

56.2 The most comprehensive method for this task is a computerized finite element analysis (FEA). There has been very good correlation between FEA results and destructive laboratory tests.

57. Weathering

57.1 Natural stone products, in general, exhibit remarkable resistance to weathering exposure. There are some types of dimension stones with less desirable weathering characteristics, and there are some specific climates that may attack certain stone types.

57.2 The development of a laboratory test to replicate, in an accelerated time frame, the effects of natural weathering exposure is currently a topic of study of Subcommittee C18.01 on Dimension Stone Test Methods. As this is a very complex issue, encompassing many different stone types and climatic conditions, it may be some time before a standard laboratory test is endorsed as being reasonably correlative to natural weathering effects. Until such a test is fully developed, the designer is best advised to research the performance of the particular stone species in the same or similar climatic environment on existing structures. Most dimension stone suppliers keep databases of existing projects and are willing to share that information to anyone wishing to observe the performance of existing applications.

58. Anticipated Durability

58.1 As stone is the oldest building material known to man, most of the oldest structures in any society are built of, or clad in some type of stone product. However, modern architectural applications of stone, in which relatively thin panels rely on the flexural strength of the stone, require a much greater understanding of some stone properties than were needed for cubic, load-bearing stone structures. In addition, modern construction methods include many components and materials in conjunction with the dimension stone, some of which may have shorter service lives than the stone.

58.2 Once the desired service life of the building is established, the designer is required to ensure that all components either meet or exceed that service life, or are readily repairable/replaceable through regular maintenance activities. All concealed items, such as support and anchorage hardware, must be made from a durable, corrosive-resistant material that will meet the anticipated service life of the building.

DIMENSION STONE TESTING

59. Introduction

59.1 Currently, ASTM publishes 12 test methods applicable to dimension stone. A brief summary of each is provided as follows:

59.1.1 *Test Methods C 97*—These test methods cover the determination of the water absorption and bulk specific gravity of all types of dimension stone, except slate. The test specimens may be cubes, rectangular prisms, cylinders, or any regular form with least dimension not less than 51 mm (2 in.), greatest dimension not more than 76 mm (3 in.), and surface area to volume ratio not less than 0.3 nor more than 0.5. A sawn finish or better is prescribed for all surfaces.

59.1.2 *Test Method C 99*—This test method covers the determination of the modulus of rupture of all types of dimension stone, except slate. Modulus of rupture is reported as the flexural breaking stress of a 57-mm (2¼-in.) thick, 102-mm (4-in.) wide, 203-mm (8-in.) long beam, with simple supports spanning 178 mm (7 in.) and loaded at the center. A smooth ground finish is prescribed for all surfaces. Test methods are typically performed on wet and dry specimens with the supports oriented parallel and perpendicular to the stone rift or bedding plane.

59.1.3 *Test Methods C 120*:

59.1.3.1 These test methods cover determination of the modulus of rupture and flexural modulus of elasticity of structural, electrical, and roofing slate. Structural and electrical slate tests utilize 25-mm (1-in.) thick, 32-mm (1¼-in.) wide, 305-mm (12-in.) long samples placed on simple supports spanning 254 mm (10 in.) and loaded at the center. A smooth ground finish is prescribed for all surfaces. Test methods are typically performed on dry specimens with the supports oriented parallel and perpendicular to the stone bedding plane.

59.1.3.2 Roofing slate test methods utilize 102-mm (4-in.) square samples with split faces and a thickness of 5 mm (3⁄16 in.), placed on simple supports spanning 51 mm (2 in.) and loaded at the center. Test methods are typically performed on dry specimens with the supports oriented parallel and perpendicular to the stone bedding plane.

59.1.4 *Test Method C 121*—This test method covers the determination of the water absorption of slate. Square or rectangular test samples 5 to 8 mm (3⁄16 to 5⁄16 in.) thick with split faces and measuring not less than 102 mm (4 in.) on any side are used.

59.1.5 *Test Method C 170*—This test method covers the determination of the compressive strength of all dimension stones. Compressive strength is reported as the failure stress under uniaxial compression. Test specimens may be cubes, rectangular prisms, or cylinders with a diameter or lateral dimension not less than 51 mm (2 in.), and a ratio of height to diameter or lateral dimension not less than 1:1. Test methods are typically performed on wet and dry specimens with the compressive load applied parallel and perpendicular to the stone rift or bedding plane.

59.1.6 *Test Method C 217*—This test method covers two procedures for determining weather resistance of slate as indicated by the depth of softening caused by submersion in a solution of 1 % sulfuric acid, as measured by a commercial scratch tester or by hand scraping. Test specimens measuring 51 mm (2 in.) by 102 mm (4 in.) with split faces are used.

59.1.7 *Test Method C 241*—This test method covers the determination of the abrasion resistance of all types of dimension stones where the wear is caused by the abrasion of foot traffic. Test specimens 51 mm (2 in.) square by 25 mm (1 in.) thick, with sawn faces are used. Abrasion resistance is reported as a dimensionless ratio related to weight loss incurred during 225 revolutions of grinding in a custom-fabricated test machine with a prescribed abrasive grit. The prescribed abrasive is no longer available, and has been the replaced with a more aggressive material, resulting in lowered test values. Test Method C 1353 has been devised as a replacement for this test method.

59.1.8 *Test Method C 880*—This test method covers the determination of the flexural strength of all dimension stones, except slate. Flexural strength for standard specimens is reported as the flexural breaking strength of a 32-mm (1¼-in.) thick, 102-mm (4-in.) wide, 381-mm (15-in.) long beam, with simple supports spanning 320 mm (12½ in.) and quarter-point loading. A smooth ground finish is prescribed for all surfaces. Test specimens with thicknesses and surface finishes specified for use on a specific construction project can also be used. Test methods are typically performed on wet and dry specimens with the supports oriented parallel and perpendicular to the stone rift or bedding plane.

59.1.9 *Test Method C 1201*—This test method covers the determination of the structural performance of dimension stone cladding systems under positive and negative uniform static air pressure differences, using a test chamber to represent the effects of wind loads on exterior building surface elements. All parts of the test specimens are full size, using the same materials, material finishes, details and methods of anchorage used, or planned to be used, on a specific construction project. Test methods are typically performed on dry stone specimens, however wet tests can also be performed.

59.1.10 *Test Method C 1352*—This test method covers the procedure for determining the flexural modulus of elasticity of all dimension stones, except slate. Flexural modulus of elasticity for standard specimens is reported as the slope the load/deflection curve of a 32-mm (1¼-in.) thick, 102-mm (4-in.) wide, 381-mm (15-in.) long beam, with simple supports spanning 320 mm (12½ in.) and quarter-point loading. A smooth ground finish is prescribed for all surfaces. Test specimens with thicknesses and surface finishes specified for use on a specific construction project can also be used. Test methods are typically performed on wet and dry specimens with the supports oriented parallel and perpendicular to the stone rift or bedding plane.

59.1.11 *Test Method C 1353*—This test method covers the determination of the abrasion resistance of all types of dimension stone for floors, steps, and similar uses where the wear is caused by the abrasion of foot traffic. Abrasion resistance is reported as a dimensionless ratio related to weight loss incurred during 1000 revolutions of grinding in a commercial test machine fitted with prescribed abrasive wheels. Standard test specimens 102 mm (4 in.) square by 10 mm (⅜ in.) thick, with smooth ground faces are used. Alternately, test specimens with surface finishes specified for use on a specific construction project can also be used.

59.1.12 *Test Method C 1354 Test Method*—This test method covers the determination of the ultimate strength of the stone at the anchorage points. This test method is intended to represent the interaction of the anchor with the stone panel, however it is not intended to be a test method for determining the strength of the entire mechanical anchorage assembly. Influence of the backup structure is not included in the test fixturing. Test methods are typically performed on wet stone specimens, however dry test methods can also be performed.

SELECTION PROCESS

60. Outline of Process

60.1 To best match a stone to a project's architectural and durability requirements, compare the following aspects for several stones in an analysis matrix early in design development: appearance, availability, total cost, proven durability, structural properties, and fabrication limits.

61. Appearance

61.1 Identify intended appearance by referring to an existing building's material or a sample with its source. Name the color and finish texture. Many materials from the same geological source are given proprietary names by different producers, but appear alike. Several finishes created by the same fabrication process are named differently by different producers, while some finishes appear identical, but are produced differently.

61.2 Identify a range mutually agreeable between the designer and the producer by referencing published brochures, catalogues, or by observing recent buildings using the material. Because stone is a natural material, its appearance varies. Range of variation is different for each stone type and finish.

61.3 Confirm the range by selecting a group of samples produced from freshly quarried material in the project's finish, showing extremes in appearance of currently available stone. Size must be large enough to show characteristics of the extremes and their context. View samples under natural light in both wet and dry conditions. View samples from a distance and oblique angle when intended for a tall project.

61.4 Rank stones under consideration in preference order based on appearance in accordance with Section 67.

62. Availability

62.1 Verify that enough stone can be produced in the quality required within the project schedule. Many stones can be obtained from only one quarry. Quarry size, climate, and location of quarry dictate physical availability. Whether foreign or domestic, commitments to other projects, exclusive distributor agreements, cost engineering or testing decisions control or influence availability.

62.2 Rank stones under consideration according to their availability in accordance with Section 67. Materials having the highest availability are readily available to any fabricator. Less available materials are accessible to a limited number of fabricators, and least available are single fabricators or quarries. Maximum availability minimizes direct material cost and impact on project schedule.

63. Total Cost

63.1 Approximate an installed cost by comparing the production plus installation costs for each material being considered.

63.2 For production, total cost includes influence of thickness, panel size, replicated sizes, fabricator's proximity to quarry, project's proximity to fabricator, domestic or foreign source, crating requirements, and shipment method.

63.3 For installation, total cost includes anchors and backup support which vary for different stone types depending upon their structural properties, installation method (handset on-site or off-site set onto precast, truss, or curtainwall units), and maintenance after completion.

63.4 Ask specialty contractors for an installed price in the project location giving them a representative quantity of the typical panel size, finish, and thickness for the project. Also show proportion of project that is not typical and some characterization of how different the nontypical areas are from the typical.

63.5 Rank the materials into groups based on cost or at least relative cost, since pricing during early design is speculative in accordance with Section 67.

64. Durability

64.1 Assess the durability of all dimension stones under consideration. Where possible, inspect existing applications constructed with the materials under consideration. Proven performance on buildings in exposures similar to the project is the best currently available indicator of durability.

64.2 Where exemplars are not available, or are too young to offer proof of having withstood the test of time, review test data for durability where available, and assess physical properties that could indicate durability in the project's conditions.

64.3 Inspect the quarry waste piles and ledges for staining or discoloration over time. Materials from new quarries will require more rigorous laboratory evaluation of durability because of the lack of existing buildings to prove their long-term performance.

64.4 Rank the materials into groups based on their proven durability in use in the manner proposed for the particular project in accordance with Section 67. Highest has multiple exemplars in the project's location of equal or greater age than the anticipated service life of the new project. Lowest would have no exemplars or rigorous accelerated weathering laboratory testing directly evaluating the materials performance. Materials demonstrating unsatisfactory performance on existing applications should be excluded from the list of candidates.

65. Structural Properties

65.1 Obtain data on the structural properties of each dimension stone under consideration by studying results of ASTM standard test methods. Initial review of previous test data will indicate whether the physical properties for each material under consideration match conceptual panel size and support requirements. Consult Guide C 1242 to determine the extent of further testing required prior to final selection and certainly before final engineering.

65.2 Confirm the physical properties that comply with the relevant ASTM standard specification and preliminary project requirements. More importantly, study the variability of critical stress properties that directly affect design values, safety factors, thickness, and anchor size. Do a preliminary analysis of common panels supported as conceived under loads defined for cladding, not the main structure, to confirm that the architectural concept is valid. Rank the dimension stones into the following categories in accordance with Section 67:

65.2.1 Structural properties greater than required,

65.2.2 Properties meet required criteria, and

65.2.3 Properties do not conform with requirements.

66. Fabrication Limits

66.1 All materials have some limitation on finished product size and shape due to the geological characteristics, quarry operations, physical material properties, and fabrication equipment. These limitations can include the following: block size (and hence slab dimensions), types of finishes, presence of veins or inclusions, presence of fractures, direction of rift, bedding, grain, or pattern, and consistency of color or pattern.

66.2 Understanding the limitations of the stone is important to ensure that the preferred stone can be used in the manner intended for the given project, or that the architectural design is refined to match the stone's limits.

66.3 Investigate fabrication limitations by consulting with suppliers, and if possible, by inspecting the quarry and factory. After adding production committed to other projects, check quantity output for typical work; special sizes, and irregular cross sections as they apply to the project. Pay particular attention to capabilities for drilling or cutting for anchors accurately.

66.4 Verify the facility has a dedicated project manager or expeditor who can be contacted to coordinate progress, deliveries, payments, and replacements for damaged or otherwise unacceptable work.

66.5 Check the quality control program to confirm that slabs are checked for soundness before cutting-to-size, the thicknesses and face sizes are checked before packaging, the finishes and visual characteristics are checked against approved range samples, the anchor holes and slots are inspected for accuracy, and the crating is structurally sound and adequately protects the stone from damage during shipping.

66.6 Rank the materials based on any discernible fabrication limitations in accordance with Section 67.

66.6.1 Having no fabrication limitations that influence the proposed use is the best. As limitations in capacity or capability increase, that material's desirability decreases.

67. Analysis

67.1 Compile a matrix containing the ranking of each material for the six criteria listed in 60.1. Determine if the procurement process mandates selection of only a single best option, or requires two or more comparable options to compete during bidding.

67.2 With the remaining materials, identify the most important criteria for the project, and weighting each criterion accordingly. Multiply the ranking by the weighting, sum the scores for all criterions, thereby determining the preferred material by comparing the final score.

68. Keywords

68.1 dimension stone; dimension stone testing; finishes; granite; limestone; marble; natural stone; natural stone finishes; quartz-based; selection; slate; stone; stone evaluation; stone selection