

# Feasibility analysis of granitic rocks for use in the dimension stone industry

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## Abstract

This study presents two objective evaluation tools for assessing the feasibility of granitic rocks in dimension stone applications. The developed methods integrate fundamental physical and mechanical properties, including dry density ( $\rho_d$ ), effective porosity ( $n_e$ ), P-wave velocity ( $V_p$ ), uniaxial compressive strength (UCS), and Böhme abrasion value (BAV). Feasibility analyses based on the conditional formatting (CF) and ranking method RM reveal that the adopted input parameters are essential for determining the suitability of granitic rocks as dimension stones. The strong relationship between the CF and RM results highlights their consistency and broad applicability. Both methods exhibit good agreement with the recommendations of the American standard for granitic rocks. Consequently, the suggested methods provide practical guidance for selecting suitable rock exposures in field studies, also offering a time- and energy-efficient decision-making framework for the dimension stone industry. To comprehensively evaluate the strengths and limitations of the proposed approaches, it is recommended that these tools be applied to a wider range of dimension stone types and geological settings.

## Keywords:

granitic rocks, dimension stones, rock feasibility, conditional formatting, ranking method

## 1. Introduction

Dimension stones have been environmentally friendly construction and building materials for centuries due to their durability and aesthetic properties. They play a significant role in preserving historical and cultural considerations in several ways, linked to geographical diversity, architectural traditions, and cultural significance (Cassar et al., 2014; Pereira, 2023). Additionally, the appropriate use of dimension stones contributes to both regional and global economies (Stone, 2015). In this context, high-quality dimension stones are highly preferred in most engineering projects for several reasons. For example, dimension stones like granite and basalt often exhibit higher durability and strength properties compared to many other construction and building materials, such as wood, tile, and standard concrete mixtures.

The relative quality of dimension stones is primarily associated with physical and mechanical rock properties such as water absorption by weight ( $w_a$ ), dry density ( $\rho_d$ ), flexural strength (FS), uniaxial compressive strength (UCS), and Böhme abrasion value (BAV) (Çobanoğlu et al., 2015; Bellopede et al., 2015; Strzalkowski et al.,

2020; Amirkiyaei et al., 2021; Ahmed et al., 2021; Briševac et al., 2023; Çelik et al., 2025). These properties provide a solid basis for assessing the durability of dimension stones. In some cases, geometric quality is also essential for obtaining desirable rock blocks in dimension stone manufacturing (Hazrathosseini and Mahdevvari, 2019). Dimension stones can be specified for particular areas based on previous experiences and some national and international specifications. For example, American standards (ASTM 615-03 2004; ASTM 503-08a 2008) for dimension stones specify certain technical requirements based on different rock lithologies (see Table 1). On the other hand, European standards do not define any requirements for dimension stones based on various physical and mechanical rock properties. They would rather define some testing methods to evaluate the quality of dimension stones.

In this context, Strzalkowski et al. (2023) put forward some evaluation criteria for assessing natural stone products based on some European standards (see Table 2). Additionally, dimension stones also have dimensional standards for various applications. Some dimensional standards for granitic dimension stones are given in Table 3. Apart from these standards, impact resistance is another crucial mechanical property in dimension stones, such as granite, marble, limestone, and sandstone, which are cut to specific sizes for use in construction and decoration.

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**Table 1.** American standards for marble and granite dimension stones

Rock type	Dry density, $\rho_d$ (g/cm <sup>3</sup> )	Water absorption by weight ( $w_a$ , %)	Uniaxial compressive strength, UCS (MPa)	Flexural strength, FS (MPa)	Standard
Granite	$\geq 2.56$	$\leq 0.40$	$\geq 131$	$\geq 8.27$	ASTM 615-03 (2004)
Marble	$\geq 2.59$ (limestone) $\geq 2.80$ (Dolomite)	$\leq 0.20$	$\geq 52$	$\geq 7.00$	ASTM 503-08a (2008)

**Table 2.** Quantitative classification for dimension stones (Strzałkowski et al., 2023)

Criterion I $\rho_d$ (g/cm <sup>3</sup> )	Criterion II $n_c$ (%)	Criterion III BAV (cm <sup>3</sup> /50cm <sup>2</sup> )	Criterion IV UCS (MPa)	Criterion V FS (MPa)	Classification
< 1.5	> 16.0	> 55	< 15	< 4	Very low
1.5 – 1.8	11.0 – 16.0	40 – 55	15 – 50	4 – 8	Low
1.8 – 2.2	6.0 – 11.0	25 – 40	50 – 120	8 – 12	Moderate
2.2 – 2.6	1.0 – 6.0	10 – 25	120 – 200	12 – 16	High
> 2.6	< 1.0	< 10	> 200	> 16	Very high

Explanations:  $\rho_d$ : Dry density,  $n_c$ : effective porosity, BAV: Böhme abrasion value, UCS: Uniaxial compressive strength, FS: Flexural strength

**Table 3.** Nominal thickness of dimension stones offered by major authorities (ASTM C1528, 2008)

Thickness (mm)	Application
10	Floor tile thickness
20	Interior cladding, interior flooring, or furniture applications
30/32	Minimum thickness suitable for most exterior applications
40/50	Applicable to exterior cladding for standard panels
80	Applicable to exterior cladding for large panels
100	Appropriate thickness for landscape purposes (curbs, coping, steps or foundations)
150/200	Appropriate thickness for cubic materials.

It describes the ability of a natural stone to absorb sudden shocks or loads without fracturing (Sariisik, 2012; Sariisik et al., 2016). In the British standards (BS EN 1467 2005; BS EN 1469 2006), the impact resistance of natural stones ( $\geq 6$  MPa) has been emphasised to measure their relative quality.

Tables 1–3 provide a solid basis for quantifying the quality of dimension stones and identifying potential usage areas based on their dimensions. However, it is worth reminding that while a rock type may meet one quantitative specification, such as  $w_a$ , it may fall short of others like UCS and BAV. Under these circumstances, additional laboratory studies or objective decision-making tools are required to determine whether related rock types should be further investigated for their potential use in the industry. Engineering judgment for material selection should be based on the feasibility assessments

that consider the determination of physical and mechanical rock properties. Therefore, additional laboratory tests or objective quantitative approaches help stakeholders make informed decisions.

Multi-decision evaluation tools can save time and energy, ensuring the efficient use of natural resources. Moreover, they play a crucial role in environmental protection by guiding decisions on the further utilization of specific rock types (Esmailzadeh et al., 2025).

Essentially, due to various constraints or a lack of opportunities, it may not always be feasible to conduct detailed laboratory tests to assess rock suitability, particularly in field studies. In cases of limited quantitative data, objective evaluation methods can offer valuable insights into rock feasibility. Based on the above description, this study proposes two quantitative approaches to evaluate the feasibility of dimension stones. As a case study, granitic rocks are adopted since they are among the most desirable rock lithologies, together with basalt and marble, in the dimension stone industry. A comprehensive literature survey is conducted to collect quantitative data on granitic rocks. Then, several assessment criteria are adopted to thoroughly investigate the suitability of granitic rocks for use as dimension stones. In the last part, the findings obtained from the two methods are compared.

## 2. Materials and methods

### 2.1. Data gathering

Previous research articles in rock mechanics and engineering geology have been reviewed to gather quantitative data on granitic rocks. As a result of this survey, 134 granitic rock samples were considered. It is worth

**Table 4.** Collected data for granitic rocks

Country	$\rho_d$ (g/cm <sup>3</sup> )	$n_e$ (%)	$V_p$ (km/s)	UCS (MPa)	BAV (cm <sup>3</sup> /50cm <sup>2</sup> )	n	Reference
Portugal	NR	0.51 – 6.15	2.32 – 4.78	38.92 – 159.8	NR	8	Vasconcelos et al. (2008)
China	2.77	0.66	NR	135.73	NR	1	Tan et al. (2011)
Turkey	2.60 – 2.64	0.32 – 0.43	NR	155.9 – 168.0	4 – 4.7	2	Ersoy et al. (2005)
Turkey	NR	NR	4.05 – 5.35	94.0 – 141.5	NR	12	Er and Tuğrul (2016)
China	2.54	0.33	3.66	159.42	NR	1	Xu et al. (2021)
India	2.62	0.12	5.49	68.08	NR	1	Gautam et al. (2018)
Turkey	2.61 – 2.67	0.6 – 1.09	NR	111.77 – 155.98	NR	3	Karaca et al. (2012a)
Turkey	2.63	0.54	5.53	155.33	6.83	1	Çobanoğlu and Çelik (2017)
Iran	2.54 – 2.85	0.84 – 3.26	NR	97.2 – 152.2	NR	14	Farhadian et al. (2021)
Turkey	2.57 – 2.75	0.27 – 1.21	NR	NR	10.08 – 21.42	13	Teymen (2024)
Turkey	2.72	1.03	NR	131.44	4.34	1	Karaca et al. (2010)
Turkey	2.56 – 2.76	0.12 – 0.70	NR	118.53– 181.41	3.05 – 5.17	4	Karaca et al. (2012b)
Sweden	2.74	NR	NR	227	NR	1	Nicksiar and Martin (2012)
Malaysia	2.05 – 2.76	NR	2.70 – 8.55	15.0 – 204.9	NR	46	Armaghani et al. (2015)
Saudi Arabia	NR	0.16 – 2.05	4.11 – 5.21	156 - 198	2.25 – 10.2	26	Alsaiani and El Aal (2021)
NR: Not reported.					Total	134	

**Table 5.** Statistical descriptions of the variables involved in the analyses

Variable	n	Mean	St. Dev	Minimum	First quartile, Q <sub>1</sub>	Third quartile, Q <sub>3</sub>	Maximum
$\rho_d$ (g/cm <sup>3</sup> )	88	2.626	0.107	2.05	2.59	2.67	2.85
$n_e$ (%)	75	1.181	0.871	0.115	0.668	1.50	6.15
$V_p$ (km/s)	95	4.848	1.017	2.32	4.32	5.37	8.55
UCS (MPa)	121	127.53	45.494	15.00	96.60	164.00	227.00
BAV (cm <sup>3</sup> /50cm <sup>2</sup> )	47	8.103	3.707	2.25	5.25	10.26	21.420

Explanations:  $\rho_d$ : Dry density,  $n_e$ : Effective porosity, UCS: Uniaxial compressive strength,  $V_p$ : Pulse wave velocity, BAV: Böhme abrasion value, n: number of datasets

noting that the number of datasets (n) for adopted studies varies. This variation may arise from factors such as data availability, the focus of previous studies, and the specific parameters measured. The collected data are presented in **Table 4**, and descriptive statistics derived from this data are listed in **Table 5**. The dataset has been used to evaluate the feasibility of granitic rocks for their potential application as dimension stones.

## 2.2. Development of assessment criteria

Several standards and technical recommendations are considered in this study to develop quality classifications. Accordingly, seven different quality classification systems (Class I – VII) are reviewed (see **Table 6**) for dimension stones. Class I and II are based on the  $n_e$

of rocks. Classes III and V are based on the UCS of rocks. The  $\rho_d$  is adopted only in Class IV. The  $V_p$  and BAV are other essential parameters for Class VI and VII, respectively.

Focusing on these quality classifications, five different evaluation criteria (EC1–EC5) are defined (see **Table 7**). The technical parameters and corresponding threshold values are crucial in determining whether granitic rock types are suitable for further investigation.

## 2.3. Data analysis methods

### 2.3.1. Conditional Formatting (CF)

CF is a practical feature in spreadsheet software such as Microsoft Excel or Google Sheets that allows users to for-

**Table 6.** Assessment criteria adopted in this study

Quality classification I		Quality classification II	
Parameter	Moos and Quervain (1948)	Parameter	Strzałkowski et al. (2023)
$n_e$ (%)	Identification	$n_e$ (%)	Identification
< 1*	Very low porosity	< 1*	Very high quality
1 – 2.5	Low porosity	1 – 6	High quality
2.5 – 5	Moderate porosity	6 – 11	Moderate quality
5 – 10	High porosity	11 – 16	Low quality
10 – 20	Very high porosity	> 16	Very low quality
> 20	Extremely high porosity		
Quality classification III		Quality classification IV	
Parameter	ASTM C615-03 (2004)	Parameter	ASTM C615-03 (2004)
UCS (MPa)	Identification	$\rho_d$ (g/cm <sup>3</sup> )	Identification
≥ 131	Appropriate for use as dimension stone	≥ 2.56*	Appropriate for use as dimension stone
Quality classification V		Quality classification VI	
Parameter	Strzałkowski et al. (2023)	Parameter	Anon (1979)
UCS (MPa)	Identification	$V_p$ (km/s)	Identification
< 15	Very low quality	< 2.5	Very low quality
15 – 50	Low quality	Low quality	Low quality
50 – 120	Moderate quality	3.5 – 4.0	Moderate quality
120* – 200	High quality	4.5* – 5.0	High quality
> 200	Very high quality	> 5.0	Very high quality
Quality classification VII		Note: *The thresholds (e.g. 120 MPa for assessment criteria V) are utilized to evaluate the suitability of granitic rocks for dimension stone applications.	
Parameter	Strzałkowski et al (2023)		
BAV (cm <sup>3</sup> /50 cm <sup>2</sup> )	Identification		
< 10*	Very high quality		
10 – 25	High quality		
25 – 40	Moderate quality		
> 55	Very low quality		

**Table 7.** Evaluation criteria adopted in CF analyses

Evaluation criterion	Adopted quality classification	Threshold value
EC1	I, II	$n_e \leq 1\%$
EC2	V	UCS ≥ 120 MPa
EC3	IV	$\rho_d \geq 2.56$ g/cm <sup>3</sup>
EC4	VI	$V_p \geq 4.5$ km/s
EC5	VII	BAV ≤ 10 cm <sup>3</sup> /50 cm <sup>2</sup>

mat, classify, and redesign cells based on specific conditions or criteria. Although CF has been primarily adopted in the social sciences (Abramovich and Sugden, 2004; Sugden et al., 2015), it can also be applied in various engineering disciplines. In this study, CF is implemented in the Microsoft Excel environment to assess the feasibility of using granitic rocks as dimension stones. In the context of CF analyses, several if-then rules and countable commands (e.g. COUNTA) are used in conjunction.

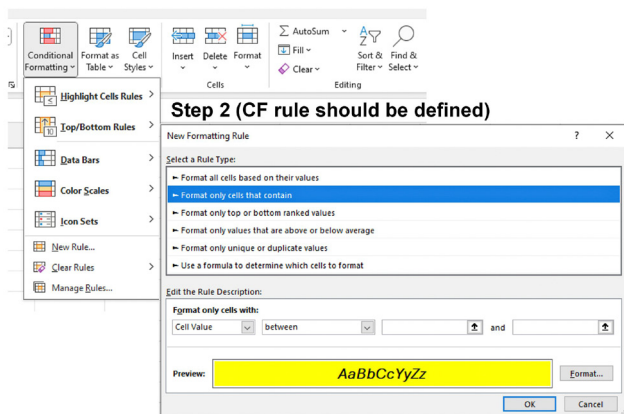
Before running the CF methodology, if-then rules should be identified based on the ECs in Table 7. Then,

three steps are defined to run CF in the Microsoft Excel environment. First, all cells that are to be analysed should be selected (Step 1). Next, the conditional formatting button should be activated to manage the rules (Step 2).

Finally, the output should be formatted to consider the font and shades that can make it more visible (Step 3). These steps are also illustrated in Figure 1.

After performing the CF, each evaluation criterion (EC1–EC5) is divided into two categories as a result: “suitable” and “unsuitable”. When assessing the feasibility of granitic rocks for their use as dimension stones, the sum of rows indicating the definition of “suitable” is considered. By implementing the “COUNTA” command in Microsoft Excel, the sum of rows indicating the definition of “suitable” and the results counted by the COUNTA command are compared. If this ratio (number of suitable cases/cases counted by COUNTA) is higher than 0.65, then the investigated granitic rock can be further investigated (continue to investigate: CTI). Otherwise, further investigation may be abandoned (FIMA) for the specific rock type being investigated.

Step 1 (Define the cells then click on the CF button)



Step 3 (format the output\* then complete the CF)

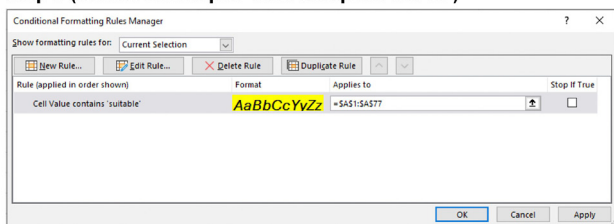


Figure 1. Steps for running the CF feature in Microsoft Excel

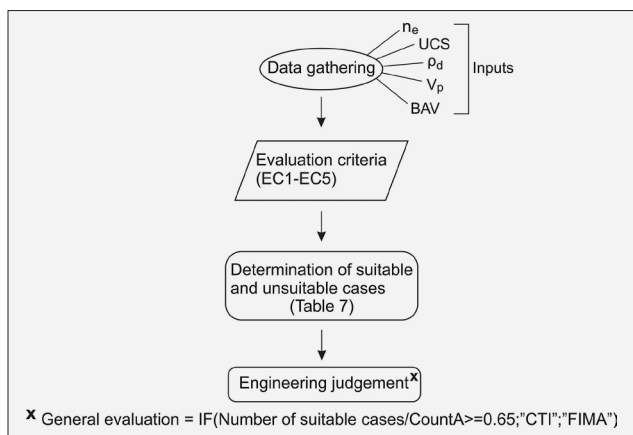


Figure 2. Flowchart of the CF process. (CTI: Continue to investigate, FIMA: Further investigation may be abandoned)

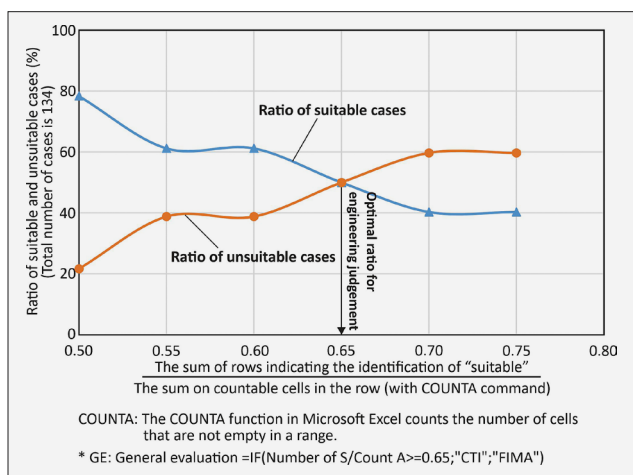


Figure 3. Optimization of the threshold value for engineering judgement in CF

The flowchart of this process is given in Figure 2. This approach can speed up decision-making processes during field studies that focus on exploring rock types that can be evaluated as potential dimension stone resources. The optimisation of the threshold value (0.65) was determined by considering several simulations. More profoundly, it was found by attempting different threshold values until a balanced evaluation (50% suitable and 50% unsuitable cases) was reached. The goal behind this was to identify a threshold value that yielded a balanced assessment, where the cases were evenly divided between 50% suitable and 50% unsuitable classifications (see Figure 3).

This approach ensured that the threshold value minimised bias in the evaluation process and provided a fair representation of the dataset’s characteristics. By achieving this balance, the selected threshold value enhanced the reliability of the model and ensured its applicability to real-world scenarios.

2.3.2. Ranking method (RM)

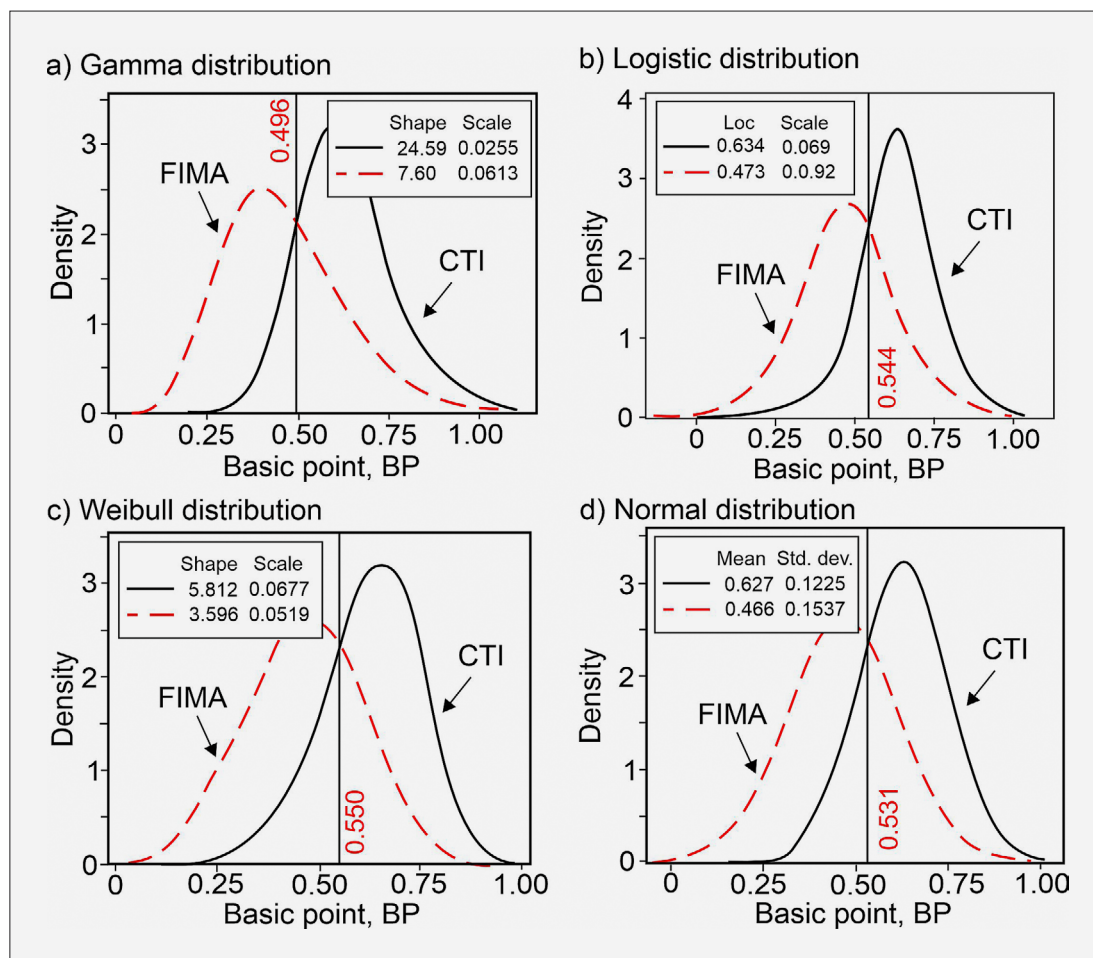
The RM in engineering judgement offers several advantages that make it a valuable tool for decision-making processes (Milanovic et al., 2010; Chang and Ku, 2021). It is mainly used in decision contexts, including project selection, risk assessment, and performance evaluation. RM is easy to comprehend, making it accessible to a wide range of users, including engineers, managers, and stakeholders. In the RM, each independent variable (i.e.  $\rho_d$ ,  $n_e$ , UCS,  $V_p$ , and BAV) is identified as a novel mathematical function (see Table 8). Thanks to these equations, each rock type has a rating point (RP), depending on each evaluation criterion.

Table 8. Mathematical functions for RM

Evaluation criterion	Formula
EC <sub>1</sub>	$RP_1 = \exp(-0.154n_e)$
EC <sub>2</sub>	$RP_2 = 0.0013UCS^{1.248}$
EC <sub>3</sub>	$RP_3 = 0.004\rho_d^5$
EC <sub>4</sub>	$RP_4 = 0.054\exp(0.42V_p)$
EC <sub>5</sub>	$RP_5 = \exp(-0.052BAV)$

Then, the average of these RPs is defined as the basic point (BP). Using the CF methodology, suitable (S) and unsuitable (US) cases are identified based on these BPs. Probability density functions (PDFs) based on Gamma, logistic, Weibull, and normal distributions are employed to establish the ranges for CMI and FIMA cases. The optimal threshold value in the RM is determined by averaging the intersection values obtained from the PDFs shown in Figure 4. In this study, the threshold value in the RM is found to be 0.53. Accordingly, BPs greater than 0.53 can be regarded as CTI.

The intersection of these PDFs in Figure 4 provides a threshold value that can be used to distinguish different



**Figure 4.** Probability density functions (PDFs) of the suitable and unsuitable cases based on different distributions a) Gamma b) Logistic c) Weibull d) Normal.

feasibility categories. This critical value (0.53) was used to assess the feasibility of granitic rocks. Although the referred value is crucial in determining the feasibility of rocks, it is essential to note that such intersections in PDFs are frequently encountered in statistics and probability theory when analysing decision-making processes (Fox and Sturdivant, 2022). The following section compares the findings obtained from the two proposed methods.

### 3. Results and Discussion

#### 3.1. CF analysis results

CF analysis results for selected case studies are listed in Table 9. Accordingly, the investigated granitic rocks can be easily characterised in terms of their potential use as dimension stones. As shown in Table 9, sufficient input data enables a reliable feasibility assessment in some cases, whereas limited input data can negatively impact the performance of the CF method. In such cases, it is recommended to conduct additional tests (at least three measurable rock parameters as described in this study) before reapplying the CF methodology. The initial re-

sults in Table 9 highlight the importance of comprehensive datasets in evaluating rocks for dimension stone applications. Rocks with well-documented properties can be assessed more confidently using the CF approach, while those with limited input data may yield uncertain evaluations, necessitating further testing to determine their suitability.

Nonetheless, in most cases, the CF methodology is easy to implement and can be effectively used to assess the feasibility of rocks for potential use as dimension stones. However, it is important to note that the threshold value (0.65) used in the CF methodology may be somewhat conservative, especially when limited data are available. This strict boundary could exclude certain rock types that may still deserve further investigation. Therefore, to apply the proposed methodology effectively, at least three measurable evaluation criteria must be satisfied.

#### 3.2. RM analysis results

The RM analysis results are presented in Table 10. Accordingly, granitic rocks with BP values greater than the threshold value (0.53) may deserve further investiga-

Table 9. CF analysis results for some cases

Case	Parameter			Evaluation criterion					Count A (y)	x/y	GE*	Reference		
	n <sub>c</sub> (%)	UCS (MPa)	ρ <sub>d</sub> (g/cm <sup>3</sup> )	V <sub>p</sub> (km/s)	BAV (cm <sup>3</sup> /50cm <sup>2</sup> )	EC1	EC2	EC3					EC4	EC5
1	0.32	155.90	2.60	NR	4.70	S	S	S	NA	S	4	1	CTI	Ersoy et al. (2005)
2	0.87	146.70	NR	4.00	NR	S	S	NA	US	NA	2	0.67	CTI	Vasconcelos et al. (2008)
3	1.50	97.2	2.70	NR	NR	US	US	S	NA	NA	1	0.33	FIMA	Farhadian et al. (2021)
4	1.33	124.80	2.66	NR	NR	US	S	S	NA	NA	2	0.67	CTI	Karaca et al. (2012b)
5	0.60	118.50	2.67	NR	3.61	S	US	S	NA	S	3	0.75	CTI	Armaghani et al. (2015)
6	NR	124.5	2.60	4.43	NR	NA	S	S	US	NA	2	0.67	CTI	Armaghani et al. (2015)
7	NR	147.1	2.61	6.48	NR	NA	S	S	S	NA	3	1	CTI	Armaghani et al. (2015)
8	1.88	164.0	NR	4.32	9.42	US	S	NA	US	S	2	0.50	FIMA	Alsaiani and El Aal (2021)
9	1.13	175.0	NR	4.61	5.64	US	S	NA	S	S	3	0.75	CTI	Alsaiani and El Aal (2021)
10	NR	227.0	2.74	NR	NR	NA	S	S	NA	NA	2	1	CTI	Nicksiar and Martin (2012)
11	0.99	NR	2.59	NR	10.29	S	NA	S	NA	US	2	0.67	CTI	Nicksiar and Martin (2012)
12	1.21	NR	2.58	NR	12.98	US	NA	S	NA	US	1	0.33	FIMA	Teymen (2024)
13	1.03	131.44	2.72	NR	4.34	US	S	S	NA	S	3	0.75	CTI	Teymen (2024)
14	0.54	153.33	2.63	5.53	6.83	S	S	S	S	S	5	1	CTI	Karaca et al. (2010)
15	NR	95.0	NR	4.32	NR	NA	US	NA	US	NA	0	0	FIMA	Çobanoğlu I. and Çelik (2017)
16	NR	124.0	NR	5.35	NR	NA	S	NA	S	NA	2	1	CTI	Er and Tuğrul (2016)

NR: Not reported, NA: Not available, S: Suitable, US: Unsuitable, CTI: Continue to investigate, FIMA: Further investigation may be abandoned.

Count A: The COUNTA function in Microsoft Excel counts the number of cells in a range that are not empty.

\* GE: General evaluation =IF (Number of S/Count A =>0.65;"CTI";"FIMA")

Table 10. RM analysis results for some cases

Case	Parameter			Evaluation criterion					BP	Threshold	GE*	Reference		
	n <sub>c</sub> (%)	UCS (MPa)	ρ <sub>d</sub> (g/cm <sup>3</sup> )	V <sub>p</sub> (km/s)	BAV (cm <sup>3</sup> /50cm <sup>2</sup> )	EC1	EC2	EC3					EC4	EC5
1	0.32	155.90	2.60	NR	4.70	0.95	0.71	0.48	NA	0.78	0.73	0.53	CTI	Ersoy et al. (2005)
2	0.87	146.70	NR	4.00	NR	0.87	0.66	NA	0.29	NA	0.61	0.53	CTI	Vasconcelos et al. (2008)
3	1.50	97.2	2.70	NR	NR	0.79	0.39	0.57	NA	NA	0.59	0.53	CTI	Farhadian et al. (2021)
4	1.33	124.80	2.66	NR	NR	0.81	0.54	0.53	NA	NA	0.63	0.53	CTI	Farhadian et al. (2021)
5	0.60	118.50	2.67	NR	3.61	0.91	0.50	0.54	NA	0.83	0.70	0.53	CTI	Karaca et al. (2012b).
6	NR	124.5	2.60	4.43	NR	NA	0.54	0.48	0.35	NA	0.45	0.53	FIMA	Armaghani et al. (2015)
7	NR	147.1	2.61	6.48	NR	NA	0.66	0.48	0.82	NA	0.65	0.53	CTI	Armaghani et al. (2015)
8	1.88	164.0	NR	4.32	9.42	0.75	0.76	NA	0.33	0.61	0.61	0.53	CTI	Alsaiani and El Aal (2021)
9	1.13	175.0	NR	4.61	5.64	0.84	0.82	NA	0.37	0.75	0.69	0.53	CTI	Alsaiani and El Aal (2021)
10	NR	227.0	2.74	NR	NR	NA	1.13	0.62	NA	NA	0.88	0.53	CTI	Nicksiar and Martin (2012)
11	0.99	NR	2.59	NR	10.29	0.86	NA	0.47	NA	0.59	0.64	0.53	CTI	Nicksiar and Martin (2012)
12	1.21	NR	2.58	NR	12.98	0.83	NA	0.46	NA	0.51	0.60	0.53	CTI	Teymen (2024)
13	1.03	131.44	2.72	NR	4.34	0.85	0.57	0.60	NA	0.80	0.70	0.53	CTI	Teymen (2024)
14	0.54	153.33	2.63	5.53	6.83	0.92	0.69	0.50	0.55	0.70	0.67	0.53	CTI	Karaca et al. (2010)
15	NR	95.0	NR	4.32	NR	NA	0.38	NA	0.33	NA	0.36	0.53	FIMA	Çobanoğlu I. and Çelik (2017)
16	NR	124.0	NR	5.35	NR	NA	0.53	NA	0.51	NA	0.52	0.53	FIMA	Er and Tuğrul (2016)

NR: Not reported, NA: Not available, CTI: Continue to investigate, FIMA: Further investigation may be abandoned.

\* GE: General evaluation = IF (BP=>Threshold value (0.53);"CTI";"FIMA")

tion. In this context, the results obtained from the RM analysis are in good agreement with those obtained from the CF methodology. However, it is worth noting that each evaluation criteria (EC1 – EC5) are weighted equally in the RM.

To address the dominance of input parameters, it is possible to assign the relative weights of input parameters based on the specific engineering context of dimension stones. Since each rock type has pros and cons depending on its inherent nature, by carefully assigning appropriate weights to each input parameter according to their relative importance, the dominance of any single input parameter can be regulated. This approach helps mitigate biases and ensures that the RM can accurately reflect the suitability of granitic rocks for dimension stone applications based on comprehensive and well-balanced evaluation criteria.

### 3.3. Discussion

Dimension stone quality assessment is conducted based on the quantitative rock properties. In this context, it has been noted that the fundamental input parameters can be defined as  $\rho_d$ ,  $w_a$ , UCS, FS, and BAV for assessing rock feasibility (Strzalkowski et al., 2023; Strzalkowski and Köken, 2024). However, geochemical and textural properties become prominent in assessing the quality of granitic rocks (Ersoy and Acar, 2016; Lasheen et al., 2023; Waqar et al., 2025). To observe the long-term behaviour and performance of granitic rocks, rock weathering effects, including freezing–thawing, heating–cooling, drying–wetting, and salt crystallisation, should be considered (Bao and Zhao, 2008; Heidari et al., 2013; Abad et al., 2016; Liu et al., 2022; Ghasera and Rashid, 2024, Maričić et al., 2025).

When evaluating the adopted methods used to assess rock feasibility, physical and mechanical rock properties are essential components in both the CF and RM. They define the evaluation criteria, influence analytical outcomes, and facilitate effective data interpretation. The selection and application of these properties should be carefully chosen in consideration of the specific requirements of dimension stone applications to ensure accurate and meaningful results. Table 11 presents the results of the proposed approaches, considering the available input parameters.

The table clearly demonstrates that the combined use of physical and mechanical parameters leads to more reliable and comprehensive outcomes.

In this context, the CF and RM-based methods exhibit strong coherence in their results and effectively complement each other, enhancing the overall robustness of the assessment process. In general, CF may have numerous practical implications, enabling one to interpret large datasets. It enables geoscientists and mining engineers to identify patterns, anomalies, and thresholds in raw tables without requiring any additional computa-

Table 11. Comparison of the suggested methods

Case	Methodology		Input parameter						American specifications for granitic dimension stones (Table 1) <sup>1</sup>		References	
	CF	RM	$n_c$	UCS	$\rho_d$	$V_p$	BAV	Criterion I ( $\rho_p, g/cm^3$ )	Criterion II (UCS, MPa)			
1	CTI	CTI	+	+	+	-	+	2.60	Suitable	155.9	Suitable	Ersoy et al. (2005)
2	CTI	CTI	+	+	-	+	-	NA	NA	146.70	Suitable	Vasconcelos et al. (2008)
3	FIMA	CTI	+	+	+	-	-	2.70	Suitable	97.2	Unsuitable	Farhadian et al. (2021)
4	CTI	CTI	+	+	+	-	-	2.66	Suitable	124.80	Unsuitable	Karaca et al. (2012b)
5	CTI	CTI	+	+	+	-	+	2.67	Suitable	118.50	Unsuitable	Armaghani et al. (2015)
6	CTI	FIMA	-	+	+	+	-	2.60	Suitable	124.5	Unsuitable	Alsaari and El Aal (2021)
7	CTI	CTI	-	+	+	+	-	2.61	Suitable	147.1	Suitable	Nicksiar and Martin (2012)
8	FIMA	CTI	+	+	-	+	+	NA	NA	164.0	Suitable	Teymen (2024)
9	CTI	CTI	+	+	+	+	+	NA	NA	175.0	Suitable	Karaca et al. (2010)
10	CTI	CTI	-	+	+	-	-	2.74	Suitable	227.0	Suitable	Çobanoğlu and Çelik (2017)
11	CTI	CTI	+	-	+	-	+	2.59	Suitable	NA	NA	Er and Tuğrul (2016)
12	FIMA	CTI	+	-	+	-	+	2.58	Suitable	NA	NA	
13	CTI	CTI	+	+	+	-	+	2.72	Suitable	131.44	Suitable	
14	CTI	CTI	+	+	+	+	+	2.63	Suitable	153.33	Suitable	
15	FIMA	FIMA	-	+	-	+	-	NA	NA	95.0	Unsuitable	
16	CTI	FIMA	+	+	-	+	-	NA	NA	124.0	Unsuitable	

<sup>1</sup> ASTM 615-03 (2004) CTI: Continue to investigate, FIMA: Further investigation may be abandoned, NA: Not available

tional software. On the other hand, RM is used to help inform multi-criteria decisions. Since RM avoid bias from different units/scales, every input parameter is put on a comparable scale, which makes its use much easier. In the natural stone industry, both CF and RM can be reliably used to analyse large datasets from different perspectives, including quality evaluation, usage area addressing, and determination of the appropriate rock exposures for dimension stone manufacturing.

The validity of the suggested approaches is further supported by comparison with results based on the American standard (see **Table 11**) for granitic rocks. The findings indicate that the cases identified as CTI by the proposed methods are largely consistent with those suitable for use as dimension stones, according to the American standard. This strong correlation highlights the reliability of the RM and CF methodologies in distinguishing between suitable and unsuitable cases, supporting their applicability in practical evaluation scenarios.

Consequently, the adoption of these objective, data-driven methods can help standardize the assessment of dimension stones and support informed decision-making in both industrial and engineering contexts.

Particularly, the implementation of CF seems to be easier than that based on RM. However, the RM can be coded in any programming language, such as MATLAB or Python, to implement it more effectively. On the other hand, the most significant challenge in any decision-making task is the availability of input parameters. Therefore, the appropriate use of these methods heavily relies on the presence of input parameters adopted in this study.

Nevertheless, it should be mentioned that at least three measurable rock properties should be identified to run the CF more effectively. On the other hand, RM can be successfully applied to assess the feasibility of dimension stones by considering the input parameters adopted. The suggested method based on RM can also be arranged or modified by considering different input parameters. This flexibility increases its potential use in the dimension stone industry. Finally, although the proposed methods are in good agreement with the American Standard (**ASTM 615-03, 2004**), they should be applied to different granitic rocks to observe their advantages and limitations.

#### 4. Conclusions

This study presents two objective evaluation tools for assessing the feasibility of using granitic rocks as dimension stone. The feasibility analysis reveals that the selected input parameters ( $\rho_d$ ,  $n_c$ ,  $V_p$ , UCS, and BAV) are crucial for accurately determining the suitability of rocks as dimension stones. The results indicate that the proposed CF and RM approaches offer practical support for selecting appropriate rock exposures in field studies. Additionally, these methodologies provide a time- and energy-efficient solution, enhancing decision-making within

the dimension stone industry. The strong agreement between the CF and RM methods highlights their consistency and wider applicability. Furthermore, both techniques show good compatibility with the American standard recommendations for granitic rocks, supporting their validity and relevance in real-world applications.

Beyond technical robustness, integrating CF and RM tools can promote more sustainable resource management by lowering unnecessary quarrying activities, including laboratory testing and analysis, and minimising economic and environmental risks. Their flexibility makes them especially useful for preliminary assessments where quick yet reliable results are needed, such as in early exploration, project planning, and investment decisions. However, to better understand the strengths and possible limitations of these methods, it is recommended to test them on a wider variety of dimension stone types and geological settings. Future research should focus on validating and refining these tools through more case studies to demonstrate their robustness and versatility for various applications within the natural stone industry, while also investigating the potential for digital integration with technologies like GIS, machine learning, and remote sensing to further improve prediction accuracy and practical use.

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## SAŽETAK

### Analiza upotrebljivosti granitnih stijena u industriji arhitektonsko-građevnoga kamena

Ovom studijom predstavljena su dva objektivna alata za ocjenjivanje upotrebljivosti granitnih stijena u industriji arhitektonsko-građevnoga kamena. Razvijene metode integriraju temeljna fizička i mehanička svojstva, uključujući suhu gustoću ( $\rho_d$ ), efektivnu poroznost ( $n_e$ ), brzinu P-valova ( $V_p$ ), jednoosnu tlačnu čvrstoću (UCS) i Böhmeov indeks abrazije (BAV). Analize pogodnosti temeljene na uvjetnome formatiranju (CF) i metodi rangiranja (RM) pokazale su da su odabrani ulazni parametri ključni za određivanje primjene granitnih stijena kao arhitektonsko-građevnoga kamena. Snažna povezanost između rezultata CF i RM potvrđuje njihovu konzistentnost i široku primjenu. Obje metode pokazale su dobro slaganje s preporukama američkoga standarda za granitne stijene. Slijedom toga, predložene metode pružaju praktične smjernice za odabir prikladnih stijenskih izdanaka u terenskim istraživanjima nudeći pritom vremenski i energetski učinkovit okvir za donošenje odluka u industriji arhitektonsko-građevnoga kamena. Za cjelovitiju procjenu prednosti i ograničenja predloženih pristupa preporučuje se primjena ovih alata na širi spektar tipova arhitektonsko-građevnoga kamena i različite geološke uvjete.

#### Ključne riječi:

granitne stijene, arhitektonsko-građevni kamen, upotrebljivost stijena, uvjetno formatiranje, metoda rangiranja

#### Author's contribution

**Ekin Köken** (PhD): conceptualization, investigation, data curation, software. The author has read and agreed to the published version of the manuscript.