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Towards stronger paving blocks: The combined effects of cement–sand mix proportion and geometry on compressive strength

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Abstract

The compressive strength of *paving blocks* is influenced not only by mix proportion but also by geometric configuration, yet comparative studies addressing both factors using local materials remain limited. This study aimed to analyze the effects of cement–sand mix proportion and *paving block* geometry on compressive strength. A quantitative experimental approach was employed through laboratory testing of two *paving block* types (*Paving Stone* and *Eskoosix*) using four cement–sand mix proportions (1:2, 1:3, 1:4, and 1:5) following SNI 03-1745-2000. The results showed that the 1:2 mix proportion produced the highest compressive strength, reaching 403.13 kg/cm² for *Paving Stone* and 401.84 kg/cm² for *Eskoosix*, whereas the 1:5 mix proportion yielded the lowest values. In addition, *Paving Stone* consistently exhibited higher compressive strength than *Eskoosix*. The findings demonstrate that mix proportion is the primary factor governing compressive strength, while *paving block* geometry contributes to optimizing stress distribution, providing a practical reference for developing local-material-based *paving blocks*.

Keywords: *Paving block*; Compressive strength; Geometry; Mix proportion; Local materials.

Abstrak

Perbedaan kuat tekan *paving block* tidak hanya dipengaruhi oleh komposisi campuran, tetapi juga oleh bentuk geometrinya, sementara kajian yang membandingkan kedua faktor tersebut pada *paving block* berbasis material lokal masih terbatas. Penelitian ini bertujuan menganalisis pengaruh variasi komposisi semen-pasir dan bentuk *paving block* terhadap kuat tekan. Penelitian menggunakan metode kuantitatif dengan pendekatan eksperimental melalui pengujian laboratorium terhadap dua tipe *paving block* (*Paving Stone* dan *Eskoosix*) dengan empat variasi campuran semen-pasir (1:2, 1:3, 1:4, dan 1:5) sesuai SNI 03-1745-2000. Hasil penelitian menunjukkan bahwa campuran 1:2 menghasilkan kuat tekan tertinggi, yaitu 403,13 kg/cm² pada tipe *Paving Stone* dan 401,84 kg/cm² pada tipe *Eskoosix*, sedangkan campuran 1:5 menghasilkan nilai terendah. Selain itu, tipe *Paving Stone* secara konsisten menunjukkan kuat tekan yang lebih tinggi dibandingkan tipe *Eskoosix*. Penelitian ini menegaskan bahwa komposisi campuran merupakan faktor dominan, sedangkan geometri *paving block* berperan dalam mengoptimalkan distribusi tegangan sehingga dapat menjadi acuan pengembangan *paving block* berbasis material lokal.

Kata Kunci: P*aving block*; Kuat tekan; Geometri; Komposisi campuran; Material lokal.

Introduction

Paving blocks are widely used as pavement materials for residential roads, sidewalks, parking areas, urban parks, and various public facilities due to their ease of installation, relatively low maintenance costs, and adaptability to different ground conditions (Yeo et al., 2021). The quality of a *paving block* is primarily determined by its ability to withstand service loads, making compressive strength the principal parameter for evaluating its structural performance (Bilir et al., 2022). High compressive strength indicates that *paving blocks* possess adequate resistance to vehicular and pedestrian loads (Mashudi et al., 2020), whereas insufficient compressive strength may lead to cracking, fracture, and a reduced service life of pavement structures (Subashi De Silva & Priyamali, 2022). Therefore, compressive strength testing is an essential step in ensuring that *paving blocks* satisfy quality standards and can be safely applied to various pavement systems.

The increasing demand for infrastructure development has encouraged the utilization of local materials as an alternative for producing high-quality and cost-effective construction materials (Manandhar et al., 2019). The use of locally sourced aggregates can reduce transportation costs, shorten production time, and enhance the economic value of regional natural resources (Silva et al., 2019). South Tapanuli Regency possesses abundant aggregate resources that have considerable potential for use as raw materials in *paving block* production (Nasution et al., 2026). However, the utilization of local materials should not rely solely on their availability but must also be supported by comprehensive evaluations of their mechanical properties to ensure compliance with technical specifications. Consequently, assessing the compressive strength of *paving blocks* manufactured from local materials is essential to verify their suitability for sustainable infrastructure development.

In addition to material characteristics, the shape or geometric configuration of *paving blocks* is also expected to influence their ability to distribute applied loads. Different geometries produce different *interlocking* mechanisms, which may affect both load-bearing capacity and the overall stability of pavement systems (Kim et al., 2025). Two commonly used geometries are the *Eskoosix* and *Paving Stone* types, each of which possesses distinct geometric characteristics. Although both are manufactured using similar constituent materials, their geometric differences are expected to produce different mechanical responses under compressive loading. Therefore, evaluating the compressive strength of these two *paving block* types is necessary to determine whether geometric variation significantly influences compressive strength and to identify the most suitable geometry for construction applications.

The influence of *paving block* geometry on compressive strength cannot be separated from the cement–sand mix proportion used during the manufacturing process (Hettiarachchi & Mampearachchi, 2019). Variations in cement content affect the density of the concrete matrix, the bonding between constituent particles, and the material's ability to resist compressive loads (Yang et al., 2025). In general, a higher cement content produces greater compressive strength, whereas reducing the cement proportion tends to decrease the mechanical performance of *paving blocks*. Therefore, comparing different *paving block* geometries can provide more objective results when the evaluation is conducted under identical material properties, specimen thickness, curing age, and production procedures while varying the cement–sand mix proportion. Such an approach enables the effect of *paving block* geometry to be observed more clearly without being influenced by differences in testing conditions or constituent material characteristics.

Numerous studies have investigated the compressive strength of *paving blocks*. Research by Farooq et al. (2023) demonstrated that increasing the cement proportion enhances the compressive strength of *paving blocks*; however, most studies have focused primarily on variations in mix proportion without comparing the influence of geometric configuration. Research by Ruki et al. (2025) found that locally sourced materials can produce *paving blocks* that satisfy quality standards when aggregate characteristics meet construction requirements, although the study emphasized material quality rather than the comparative performance of different *paving block* geometries. Furthermore, research by Zhu et al. (2022) indicated that *paving block* geometry may influence load distribution and pavement stability, yet investigations examining the combined relationship among geometry, mix proportion, and local materials within a single study remain limited. These findings reveal a research gap that warrants a more comprehensive investigation.

Based on these considerations, this study aims to analyze and compare the compressive strength of *Eskoosix* and *Paving Stone paving blocks* manufactured using locally sourced materials from South Tapanuli Regency with cement–sand mix proportions of 1:2, 1:3, 1:4, and 1:5. All specimens were produced using identical thicknesses, curing ages, and manufacturing procedures to ensure that differences in compressive strength could be evaluated objectively. This study is expected to identify the *paving block* geometry and mix proportion that provide the highest compressive strength, thereby serving as a practical reference for selecting pavement materials. In addition, the findings are expected to promote the more effective utilization of local materials, improve the quality of regional construction products, and provide valuable guidance for the development of high-performance *paving blocks* to support sustainable infrastructure development.

Method

This study employed a quantitative method with an experimental approach to compare the compressive strength of two *paving block* geometries, namely the *Paving Stone* and *Eskoosix* types, manufactured using locally sourced materials from South

Tapanuli Regency (Patience, 2017). A factorial experimental design was adopted, comprising two *paving block* geometries and four cement–sand mix proportions (1:2, 1:3, 1:4, and 1:5). Each treatment combination consisted of 10 specimens, resulting in a total of 80 *paving blocks*. All specimens were manually manufactured with a uniform thickness of 7 cm and tested after 28 days of curing to ensure adequate cement hydration and consistent testing conditions across all samples.

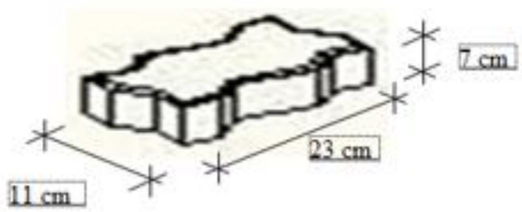
The materials used consisted of fine aggregate (sand) obtained from the Mabang Quarry, Muara Batang Toru District, South Tapanuli Regency, while *Semen Padang* Type I Portland Cement (PC) was used as the binding material. All specimens were produced using identical raw materials so that variations in compressive strength could be attributed solely to differences in *paving block* geometry and cement–sand mix proportion. The manufacturing process included material mixing, manual casting using molds corresponding to each *paving block* geometry, compaction, demolding, and curing until the designated testing age. By maintaining identical production conditions throughout the experiment, all specimens received the same treatment, allowing the test results to be compared objectively.

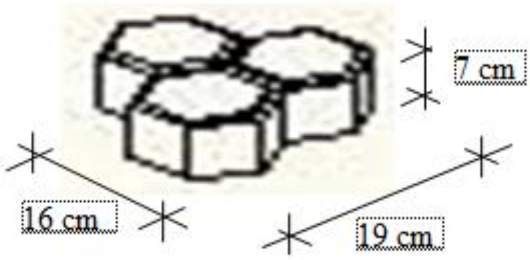
Compressive strength testing was conducted in the laboratory in accordance with SNI 03-0691-1996 for concrete paving blocks using a *Universal Testing Machine* (UTM). Each specimen was positioned securely before a gradually increasing compressive load was applied until failure occurred. The maximum load recorded at failure was subsequently used to calculate the compressive strength of each specimen based on its cross-sectional area. The experimental data were analyzed using a descriptive comparative approach by calculating the average compressive strength for each cement–sand mix proportion and *paving block* geometry. The results were then compared to identify the *paving block* geometry and mix proportion that produced the highest compressive strength, thereby providing a practical recommendation for the development of pavement materials manufactured from locally sourced materials in South Tapanuli Regency.

Results and Discussion

Compressive strength test results of *paving blocks*

This study investigated two *paving block* geometries, namely the *Paving Stone* and *Eskoosix* types, which were manually manufactured using fine aggregate obtained from the Mabang Quarry, Muara Batang Toru District, South Tapanuli Regency, and *Semen Padang* Type I Portland Cement (PC) as the binding material. All specimens were produced by UD. Lubis using identical raw materials and manufacturing procedures so that any variation in the test results could be attributed solely to differences in *paving block* geometry and cement–sand mix proportion. Both *paving block* types were manufactured with the same thickness of 7 cm and tested after 28 days of curing using a *Universal Testing Machine* (UTM). The primary differences between the two specimens were their dimensions and geometric configurations. The *Paving Stone* type measured 23 × 11 × 7 cm, whereas the *Eskoosix* type measured 19 × 16 × 7 cm. These geometric differences were expected to influence load distribution during compressive strength testing, making them suitable for comparison under identical mix proportions. The dimensions and geometries of the two *paving block* specimens are presented in Figure 1.





Paving Stone (23 × 11 × 7 cm) *Eskoosix (19 × 16 × 7 cm).*

Figure 1. Dimensions and geometric configurations of the *paving block* specimens used in this study.

Source: Developed by the authors

The compressive strength test results of the *Paving Stone paving block* under four cement–sand mix proportions are presented in Table 1. In general, increasing the proportion of sand in the mixture resulted in a substantial reduction in compressive strength. The 1:2 mix proportion produced the highest average compressive strength of 403.13 kg/cm², whereas the 1:3 mix proportion decreased to 354.80 kg/cm². A more pronounced reduction was observed for the 1:4 and 1:5 mix proportions, with average compressive strengths of 170.97 kg/cm² and 127.78 kg/cm², respectively. This trend indicates that reducing the cement proportion weakens the bonding between aggregate particles, thereby decreasing the material's resistance to compressive loading. Nevertheless, the 1:2 and 1:3 mix proportions still exhibited considerably better mechanical performance than the other mix proportions.

Table 1. Compressive strength test results of *paving stone paving blocks* under different cement–sand mix proportions.

Specimen No.	**1:2 (kg/cm²)**	**1:3 (kg/cm²)**	**1:4 (kg/cm²)**	**1:5 (kg/cm²)**
1	410.7	360.5*	175.4	132.3
2	405.5	350.5	177.0	130.0
3	400.0	365.6	173.2	135.0
4	403.5	360.0	172.0	132.0
5	402.5	366.4	173.1	124.0
6	400.5	345.5	170.0	125.0
7	405.4	355.0	170.0	122.0

8	400.0	350.0	168.0	127.5
9	403.2	354.5	166.0	120.0
10	400.0	340.0	165.0	130.0
Average	403.13	354.80	170.97	127.78

Source: Laboratory test results.

Testing of the *Eskoosix paving block* exhibited a similar trend, with compressive strength decreasing as the cement proportion was reduced. As shown in Table 2, the 1:2 mix proportion produced an average compressive strength of 401.84 kg/cm², which declined to 330.07 kg/cm² at the 1:3 mix proportion. A further decrease was observed at the 1:4 mix proportion (165.03 kg/cm²) and reached the lowest value at the 1:5 mix proportion (118.66 kg/cm²). Compared with the *Paving Stone* type, the *Eskoosix* type consistently produced slightly lower compressive strength values across all mix proportions, although both geometries exhibited a comparable pattern of strength reduction. These findings indicate that the cement–sand mix proportion is the dominant factor influencing compressive strength, while differences in *paving block* geometry may provide an additional contribution, which is discussed in the following section.

Table 2. Compressive strength test results of *eskoosix paving blocks* under different cement–sand mix proportions.

Specimen No.	**1:2 (kg/cm²)**	**1:3 (kg/cm²)**	**1:4 (kg/cm²)**	**1:5 (kg/cm²)**
1	401.2	335.5	168.4	115.6
2	410.0	334.0	168.5	120.5
3	400.5	335.8	168.0	120.0
4	400.0	332.0	170.0	120.5
5	401.0	332.1	168.6	119.5
6	400.5	334.3	166.5	119.0
7	400.7	335.0	160.8	118.0
8	402.0	320.0	160.0	119.0
9	402.5	320.5	159.0	116.5
10	400.0	321.5	160.5	118.0
Average	401.84	330.07	165.03	118.66

Source: Laboratory test results.

Overall, the experimental results for both *paving block* geometries demonstrated a consistent trend, with compressive strength decreasing as the cement proportion in the mixture was reduced. The 1:2 mix proportion produced the highest compressive strength for both *Paving Stone* and *Eskoosix*, whereas the 1:5 mix proportion yielded the lowest values. Although both geometries exhibited similar strength reduction patterns, the *Paving Stone* type consistently achieved slightly higher compressive strength than the *Eskoosix* type across all mix proportions. These findings suggest that, in addition to mix proportion, the geometric characteristics of *paving blocks* also influence their ability to distribute compressive loads. To provide a more comprehensive understanding of the performance differences between the two *paving block* geometries, a comparative analysis of their average compressive strength is presented in the following subsection.

Comparison of *paving block* compressive strength

A comparison of the average compressive strength between the *Paving Stone* and *Eskoosix paving block* geometries under different cement–sand mix proportions is presented in Table 3. Overall, both *paving block* geometries exhibited a similar trend, with compressive strength decreasing as the sand proportion in the mixture increased. However, the *Paving Stone* type consistently achieved higher compressive strength than the *Eskoosix* type across all mix proportions. The largest difference was observed for the 1:3 mix proportion, whereas the smallest difference occurred at the 1:2 mix proportion. These findings indicate that both *paving block* geometries exhibited nearly identical mechanical performance at higher cement contents but began to demonstrate noticeable differences as the cement proportion decreased. The comparison of the average compressive strength values for both *paving block* geometries is presented in Table 3.

Table 3. Comparison of the average compressive strength of *paving stone* and *eskoosix paving blocks* under different cement–sand mix proportions.

Cement–Sand Mix Proportion	***Paving Stone* (kg/cm²)**	***Eskoosix* (kg/cm²)**	**Difference (kg/cm²)**
1:2	403.13	401.84	1.29
1:3	354.80	330.07	24.73
1:4	170.97	165.03	5.94
1:5	127.78	118.66	9.12
Overall Average	264.17	253.90	10.27

Source: Laboratory test results.

Based on Table 3, the 1:2 mix proportion produced the highest compressive strength for both *paving block* geometries, reaching 403.13 kg/cm² for *Paving Stone* and 401.84 kg/cm² for *Eskoosix*. These values indicate that a higher cement content forms a denser cement paste matrix, thereby improving the material's resistance to compressive loading. When the sand proportion increased to the 1:3 mix proportion, the compressive strength of both *paving block* geometries decreased, although the *Paving Stone* type maintained superior performance with a difference of 24.73 kg/cm² compared with the *Eskoosix* type. A more pronounced reduction was observed for the 1:4 and 1:5 mix proportions, indicating that decreasing the cement content reduced the density of the concrete matrix and weakened the bonding between aggregate particles, thereby diminishing the material's capacity to resist compressive loads.

The differences in compressive strength between the two *paving block* geometries were likely influenced not only by mix proportion but also by their geometric characteristics. The *Paving Stone* geometry has a relatively simple configuration with a more uniform loading surface, allowing the applied load to be distributed more evenly during compressive testing. In contrast, the *Eskoosix* geometry features a more complex *interlocking* configuration, which may promote localized stress concentration under compressive loading. Although the differences in compressive strength between the two geometries were relatively small, the observed trend remained consistent across all cement–sand mix proportions. These findings suggest that *paving block* geometry is one of the factors influencing mechanical performance, particularly when combined with variations in cement content and fine aggregate proportion.

The findings of this study provide practical implications for selecting *paving block* geometries by considering not only their geometric characteristics but also the cement–sand mix proportion used during production. The 1:2 and 1:3 mix proportions produced substantially higher compressive strengths than the 1:4 and 1:5 mix proportions, making them more suitable for applications subjected to relatively heavy loads, such as residential roads, parking areas, and light-traffic pavements. In contrast, the 1:4 and 1:5 mix proportions are more appropriate for low-load applications, including pedestrian walkways, parks, and other landscaped areas. Therefore, the combination of the *Paving Stone* geometry and a higher cement content represents a more suitable alternative for developing pavement systems manufactured from locally sourced materials in South Tapanuli Regency.

Effect of cement–sand mix proportion and *paving block* geometry on compressive strength

The compressive strength of *paving blocks* is influenced not only by the cement–sand mix proportion but also by their geometric configuration; therefore, both factors should be evaluated simultaneously (Rachmat & Salsabilla, 2019). In the present study, the 1:2 mix proportion produced the highest compressive strength for both *paving block* geometries, reaching 403.13 kg/cm² for the *Paving Stone* type and 401.84 kg/cm² for the *Eskoosix* type. In contrast, the 1:5 mix proportion yielded the lowest compressive strengths, namely 127.78 kg/cm² for *Paving Stone* and 118.66 kg/cm² for *Eskoosix*. These results indicate that increasing the sand-to-cement ratio leads to a reduction in compressive strength. This finding suggests that both mix proportion and *paving block* geometry jointly influence the load-bearing capacity of the material. The mechanism describing the relationship between these two factors is illustrated in Figure 2.

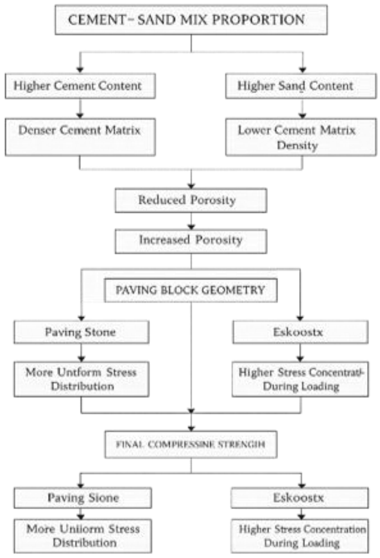


Figure 2. Schematic illustration of the influence of cement–sand mix proportion and *paving block* geometry on the compressive strength of *paving blocks*.

Source: Developed by the authors based on the experimental results.

The data presented in Table 3 indicate that reducing the cement proportion resulted in a progressive decline in compressive strength for both *paving block* geometries. For the *Paving Stone* type, the average compressive strength decreased from 403.13 kg/cm² at the 1:2 mix proportion to 354.80 kg/cm² at 1:3, before further declining to 170.97 kg/cm² at 1:4 and 127.78 kg/cm² at 1:5. A similar trend was observed for the *Eskoosix* type, where the compressive strength decreased from 401.84 kg/cm² to 330.07 kg/cm², 165.03 kg/cm², and 118.66 kg/cm², respectively. These results demonstrate that a lower cement content produces a less dense cement matrix, thereby increasing porosity and reducing the material's resistance to compressive loading. This finding is consistent with the study by Othman et al. (2021), which reported that increasing the cement content produces a denser concrete matrix and improves compressive strength. Similarly, Drissi et al. (2021) found that the increase in porosity resulting from a lower cement paste content is one of the primary factors responsible for the reduction in compressive strength of cement-based materials.

In addition to the effect of mix proportion, the results demonstrate that *paving block* geometry also contributes to compressive strength. Across all cement–sand mix proportions, the *Paving Stone* type consistently produced higher compressive strength than the *Eskoosix* type, although the differences were relatively small. The differences were 1.29 kg/cm² for the 1:2 mix proportion, 24.73 kg/cm² for 1:3, 5.94 kg/cm² for 1:4, and 9.12 kg/cm² for 1:5. These findings indicate that geometric configuration influences stress distribution during compressive loading. The *Paving Stone* geometry is likely to distribute the applied load more uniformly, resulting in greater compressive strength than the *Eskoosix* geometry. This finding is consistent with the study by Zoccali et al. (2018), which demonstrated that *paving block* geometry affects stress distribution within pavement systems. In contrast, Meesaraganda and Kakumani (2021) concluded that *paving block* geometry has no significant influence on compressive strength. However, the present study demonstrates that geometric differences consistently contribute to improved mechanical performance.

The interaction between cement–sand mix proportion and *paving block* geometry indicates that mix proportion is the primary factor governing compressive strength, whereas geometry serves as a secondary factor that optimizes load distribution. This relationship is evident for the 1:2 mix proportion, where both *paving block* geometries exhibited nearly identical compressive strengths of 403.13 kg/cm² for *Paving Stone* and 401.84 kg/cm² for *Eskoosix*, with a difference of only 1.29 kg/cm². However, the difference increased to 24.73 kg/cm² at the 1:3 mix proportion before decreasing to 5.94 kg/cm² and 9.12 kg/cm² for the 1:4 and 1:5 mix proportions, respectively. These findings suggest that as the quality of the cement matrix deteriorates because of a reduced cement content, the influence of geometric configuration on stress distribution becomes more pronounced. The present results complement the findings of Kubba et al. (2018), who emphasized the dominant role of mix proportion in determining compressive strength, while also supporting the conclusions of Zhou et al. (2020), who reported that *paving block* geometry contributes to the mechanical response of the material despite having a smaller influence than mix proportion.

The findings of this study provide practical implications for selecting appropriate *paving block* geometries and cement–sand mix proportions for different construction applications. The 1:2 and 1:3 mix proportions produced substantially higher compressive strengths for both *paving block* geometries, making them suitable for applications subjected to relatively heavy loads, such as residential roads, parking areas, and light-traffic pavements. In contrast, the 1:4 and 1:5 mix proportions yielded lower compressive strengths and are therefore more appropriate for low-load applications, including pedestrian walkways, parks, and public open spaces. From a geometric perspective, the *Paving Stone* type consistently outperformed the *Eskoosix* type across all mix proportions and may therefore be considered a more suitable alternative for pavement applications requiring higher compressive strength. This finding is consistent with the study by Tian et al. (2020), which recommended using higher cement-content mixtures to improve pavement performance. Likewise, Lin et al. (2018) emphasized that selecting an appropriate *paving block* geometry enhances load distribution efficiency and extends pavement service life. Therefore, the combination of an appropriate cement–sand mix proportion and a suitable *paving block* geometry is essential for producing locally manufactured *paving blocks* with optimum mechanical performance.

Overall, the findings demonstrate that the cement–sand mix proportion is the dominant factor governing the compressive strength of *paving blocks*, whereas geometric configuration serves as a supporting factor by influencing stress distribution during loading. The interaction between these two factors produces distinct mechanical characteristics for each *paving block* geometry, indicating that the selection of mix proportion should not be considered independently of geometric configuration. This study not only provides a comparative evaluation of the compressive strength of the *Paving Stone* and *Eskoosix* geometries but also explains the underlying mechanism through the relationship among mix proportion, cement matrix density, porosity, and load distribution. Therefore, the findings are expected to serve as a valuable reference for the development of locally manufactured *paving blocks* with improved quality while supporting more effective, efficient, and sustainable infrastructure development.

Conclusion

This study demonstrates that both the cement–sand mix proportion and *paving block* geometry jointly influence the compressive strength of *paving blocks* manufactured from locally sourced materials in South Tapanuli Regency. The 1:2 mix proportion produced the highest compressive strength for both *paving block* geometries, reaching 403.13 kg/cm² for the *Paving Stone* type and 401.84 kg/cm² for the *Eskoosix* type, whereas the 1:5 mix proportion yielded the lowest values of 127.78 kg/cm² and 118.66 kg/cm², respectively. These findings indicate that increasing the cement content produces a denser concrete matrix with lower porosity, thereby enhancing the material's resistance to compressive loading. Furthermore, the *Paving Stone* geometry consistently exhibited higher compressive strength than the *Eskoosix* geometry, suggesting that geometric configuration also influences stress distribution during loading, although its effect is less pronounced than that of the cement–sand mix proportion.

This study contributes to a better understanding of the combined effects of cement–sand mix proportion and *paving block* geometry on compressive strength through an experimental investigation using locally sourced materials, thereby providing practical guidance for selecting appropriate *paving block* geometries and mix proportions for construction applications. Nevertheless, this study is limited by the use of a single local aggregate source, a single *paving block* thickness, and an exclusive focus on compressive strength without evaluating other mechanical properties, such as water absorption, abrasion resistance, and flexural strength. Future studies are therefore recommended to incorporate a wider range of local aggregate sources, investigate different *paving block* dimensions and manufacturing techniques, and integrate compressive strength testing with additional performance parameters to provide a more comprehensive evaluation of *paving block* quality under various field conditions.

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