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Journal of Mathematics Instruction, Social Research and Opinion
Vol. 5, No. 4, December 2026, pp. 2447 – 2459, https://doi.org/10.58421/misro.v5i4.895
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Geometric Transformations and Symmetry in the Panjunan Red Mosque, Cirebon: An Ethnomathematical Study for Culture-Based Geometry Learning

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Article Info

Article history:

Received 2025-12-15
Revised 2025-12-25
Accepted 2026-11-08

Keywords:

Cultural acculturation
Ethnography
GeoGebra
Islamic architecture
Mathematics education

ABSTRACT

Historic mosques in Indonesia embody mathematical ideas, yet studies of the Panjunan Red Mosque in Cirebon, built in 1480, have focused on its history and cultural acculturation rather than its mathematical structure. This study aims to identify and map the plane geometry, solid geometry, and geometric transformations embodied in the architecture of the mosque as a source of contextual mathematics learning. A qualitative descriptive design with an ethnographic approach was used. Data were collected through direct observation, a 45–60-minute semi-structured interview with the mosque caretaker, and photographic documentation of eight architectural elements: fence ornaments, roof, pillars, walls, ventilation openings, mihrab, gate, and wall reliefs. The data were analysed with the Miles–Huberman–Saldaña interactive model using inductive open and axial coding, and the transformations were modelled schematically in GeoGebra. The elements contain squares, rectangles, circles, triangles, trapezoids and rhombuses, as well as cylinders, cuboids, a square pyramid and a pyramid frustum. Four transformations were identified: translation in the ventilation openings, approximate reflection symmetry in the mihrab and the split gate, fourfold rotational symmetry in the wall relief (dihedral group D4), and dilation in the concentric square tiers of the gate pillars. The three isometries produce congruent repetition, whereas dilation produces similar figures of decreasing size. These regularities underpin the aesthetic balance of the building and are interwoven with its Javanese, Hindu-Buddhist, Chinese and Islamic meanings. The findings can inform culture-based geometry tasks; because the models are schematic, measured dimensions and classroom trials are needed in future work.

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1. INTRODUCTION

Mathematics has developed since ancient times and has become an important component of human life. However, mathematics is often perceived as difficult to understand [1]. In fact, mathematical ideas and concepts have long been used by various cultural groups in their daily activities, even though this use is implicit and not formally structured [2].

Ethnomathematics studies the relationship between cultural practices and mathematical ideas [3]. The field was introduced by the Brazilian mathematician Ubiratan D'Ambrosio, who described ethnomathematics as the mathematics practised by identifiable cultural groups and, more broadly, as the study of how mathematical knowledge is generated and transmitted in different cultural contexts [3]. The term combines *ethno* (a cultural group or environment), *mathema* (explaining, understanding and coping with reality) and *tics* (techniques or arts) [3].

Mathematics has been part of human culture since prehistoric times and developed through the civilisations of ancient Egypt, Greece, India and China to modern European civilisation [4]. Culture itself is a product of human creation manifested as ideas, activities and artefacts [4]. Mathematics has thus been interwoven with many aspects of community life [5], and this is visible in the mathematical principles embodied in the architecture of historic buildings.

The architecture of historic buildings carries not only philosophical meaning but also mathematical principles, as shown by ethnomathematical studies of the Kacirebonan Palace in Cirebon [5], the Kauman Grand Mosque in Semarang [6], the Al-Alam Mosque in Marunda [7], the Majapahit Al Hikam Mosque in Pekalongan [8], the Kebulatan Tekad Monument [9], the Royal Carriage Museum of the Yogyakarta Palace [10] and the Sultan's Palace of Yogyakarta [11]. Beyond buildings, ethnomathematics has been documented at other cultural sites, including the ancient wells of Kaliwadas Village in Cirebon [12], the Sumenep Palace [13], the Joglo traditional house [14], Borobudur Temple [15], and the Siak Asserayah El Hasyimiah Palace [16].

Indonesia is rich in cultural diversity [17], which offers great potential for ethnomathematical study. Historic religious buildings are particularly promising objects, because they serve not only as places of worship but also as expressions of spiritual, cultural, and technical knowledge. Many old mosques in Indonesia display distinctive architecture with geometric shapes, repeated patterns, and deliberate proportions.

The Panjunan Red Mosque is one of the oldest mosques in Cirebon; its construction was initiated by Syekh Syarif Abdurrahman in 1480 [18]. As a cultural heritage site, the mosque reflects the long history of the spread of Islam and of cultural acculturation in the archipelago. Its existence is closely linked to Arab immigrants from Baghdad, Iraq, who arrived in Cirebon around the 14th century [18]. The interaction between these immigrants and local communities of various backgrounds created a distinctive cultural diversity in Panjunan Village.

The mosque is called the "Red Mosque" because it is built mainly of red brick, while "Panjunan" is the name of the village in which it stands. Its architecture synthesises Javanese, Hindu-Buddhist, Chinese and Islamic elements [19]. This fusion is evident in the walls

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decorated with porcelain plates which, according to local tradition, were a gift from the Chinese emperor to Sunan Gunung Jati [18]. The combination of red brick and porcelain is one of the visual expressions of this acculturation [19], [20].

Built by a community of Arab descent within a Javanese and Hindu-Buddhist cultural setting, the mosque became a multicultural building rich in historical, religious, and philosophical meaning [20]. Its architectural elements have been interpreted as representing Islamic values, including tolerance between cultures [21]. The cultural philosophy of the mosque has even been adapted into contemporary design, such as the "Amatris Manunggal" fashion collection [22]. This multicultural character suggests that the geometric forms and transformations embedded in the building may function as a shared visual language across these traditions, a proposition examined in this study.

From a mathematical perspective, preliminary observation shows that the architecture and ornaments of the mosque contain plane figures such as squares, rectangles, circles, triangles and trapezoids; solids such as cylinders and cuboids in the pillars and pyramidal forms in the roof; and geometric transformations—translation, reflection, rotation and dilation—in repeated and symmetrical ornamental patterns.

Symmetry generated by geometric transformations is a common organising principle of decorative and architectural traditions, and symmetry analysis is an established method for studying cultural patterns [23]. Translation, reflection and rotation are isometries, which preserve shape and size, whereas dilation preserves shape but changes size. Examining these transformations in the Panjunan Red Mosque can therefore show how mathematical regularities support the aesthetic and symbolic balance of the building, and can contribute to preserving its cultural and historical values through a scientific approach.

Although the Panjunan Red Mosque has been studied from historical, architectural, semiotic and cultural perspectives [18]–[22], these studies are largely descriptive and do not analyse the mathematical structures embedded in the building. To the best of our knowledge, no previous study has systematically mapped its geometric shapes and geometric transformations with visual documentation in an ethnomathematical context. As a result, the potential of the mosque as a source of culture-based mathematics learning has not been fully explored.

This study therefore aims to identify and analyse the plane geometry, solid geometry, and geometric transformations embodied in the structure and ornaments of the Panjunan Red Mosque, supported by photographic documentation and GeoGebra models. It also aims to show how these mathematical concepts underpin the acculturated architecture of the mosque and to outline how they can be used as culture-based mathematics learning resources, thereby strengthening the link between mathematics, culture and the preservation of Indonesia's cultural heritage.

2. METHOD

This study used a qualitative descriptive design with an ethnographic approach. Following Spradley [24], ethnography describes cultural elements in order to understand how local people interpret their environment. The approach was used to identify and describe the mathematical concepts embodied in the architecture of the Panjunan Red Mosque in

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Panjunan Village, Lemahwungkuk District, Cirebon City, West Java. Fieldwork, comprising observation, interviews, and photographic documentation, was carried out on 22 November 2025. The key informant was Ustad Muslimin, the caretaker of the mosque, who was selected purposively because of his long period of service, his involvement in maintaining the mosque, and his knowledge of the history and meaning of its ornaments.

Data were collected through (1) direct observation of the building, (2) a semi-structured interview lasting approximately 45–60 minutes, and (3) photographic documentation of eight architectural elements: the fence ornaments, roof, pillars, walls, ventilation openings, mihrab, gate (*kuta kosod*), and wall reliefs. These elements were selected because they show repeated patterns, clear geometric shapes, and observable symmetry. An example of a guiding question is: "Does this ornament have a particular symbolic or philosophical meaning?"

The data were analysed using the interactive model of Miles, Huberman and Saldaña [25], which comprises data condensation, data display and conclusion drawing/verification. Coding was inductive. Open coding identified recurring mathematical features in the observation notes, interview transcript and photographs, such as plane figures, solids and geometric transformations. Axial coding then grouped these features into six categories: shape, symmetry, angle, size, spatial pattern and type of transformation (translation, reflection, rotation and dilation). Coding was carried out by the researchers and discussed among the authors to ensure consistency of interpretation. The resulting categories were interpreted in relation to the architectural design of the mosque, its philosophical meanings, and the cultural influences on it.

GeoGebra Classic 5 was used to construct schematic models of the identified transformations. Because no on-site measurements were taken, the models are based on the photographs and use arbitrary units; they illustrate the type of transformation rather than the actual dimensions of the elements. A translation by the vector (a, b) is written $T(a, b)$: $(x, y) \rightarrow (x + a, y + b)$; a reflection in the y-axis is $(x, y) \rightarrow (-x, y)$; a rotation about the origin O through an angle θ, measured counterclockwise, is written $R(O, \theta)$; and a dilation with centre $P(a, b)$ and scale factor k is $(x, y) \rightarrow (a + k(x - a), b + k(y - b))$. The rotational and reflection symmetries of ornaments were classified using the cyclic (Cn) and dihedral (Dn) rosette groups [23].

Official permission was obtained from the management of the mosque, and the informant gave his consent to be identified by name in this article. Local norms and etiquette were respected throughout the fieldwork. Credibility was strengthened through triangulation of sources (informant, documents and literature) and methods (observation, interview and photographic documentation), and through member checking, in which the researchers' interpretations were confirmed with the informant.

3. RESULTS AND DISCUSSION

3.1. RESULTS

The analysis identified plane figures, solids, and geometric transformations in eight architectural elements of the Panjunan Red Mosque. The findings for each element are described below.

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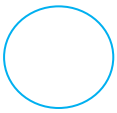
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3.1.1. Plane and Solid Geometry

Fence Ornaments

The ornaments on the fence wall display sunflower plant motifs. According to Hermana [18], the sun symbolises enlightenment for all humanity, guiding people towards faith and piety to Allah SWT.

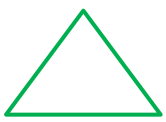
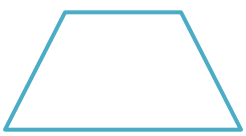
Table 1. Geometric shapes in the front fence ornaments

Overview	Geometric Shapes	Remarks
 Figure 1. Front Fence Ornaments	Square Circle 	• Square: a quadrilateral with four equal sides and four right angles; it forms the panel that frames each ornament. $A = s^2$ $P = 4s$ • Circle: the set of points at the same distance r from a centre; it forms the central disc of the sunflower motif. $A = \pi r^2$ $C = 2\pi r$

Shingle Roof

The roof is built in tiers, a concept also applied in the Great Mosque of Sang Cipta Rasa. Hermana [18] describes the pyramid-shaped, tiered shingle roof, crowned by a *memolo*, as giving the building an impression of dominant unity.

Table 2. Geometric shapes in the shingle roof

Overview	Geometric Shapes	Remarks
 Figure 2. Shingle roof	Triangle  Trapezoidal 	• Triangle: a polygon with three sides; it is the front elevation of the upper roof tier. $A = \frac{1}{2} \times base \times height$ $P = a + b + c$ • Trapezoid: a quadrilateral with exactly one pair of parallel sides; it is the front elevation of the lower roof tier. In three dimensions, the upper tier is a square pyramid and the lower tier a frustum of a square pyramid. $A = \frac{1}{2} \times (a + b) \times h$ $P = a + b + c + d$

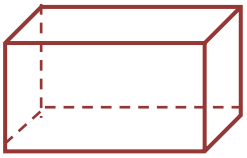
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Mosque Pillars

Field observation confirmed that the mosque has 17 main pillars supporting the roof, consistent with Hermana [18] and Nurfadli [21]. Hermana [18] interprets the number 17 as symbolising the 17 rak'ahs of the five daily prayers, so that the pillars serve as a visual reminder of prayer as the second pillar of Islam.

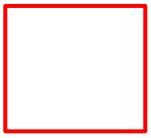
Table 3. Geometric shapes in the mosque pillars

Overview	Geometric Shapes	Remarks
 Figure 3. Mosque pillars	Cylinder  Cuboid 	• Cylinder: a solid bounded by two congruent parallel circular bases and a curved lateral surface; the round pillars are modelled as cylinders. $A = 2\pi r(r + h)$ $V = \pi r^2 h$ • Cuboid (rectangular prism): a solid bounded by six rectangular faces forming three pairs of congruent, parallel faces; the square posts are modelled as cuboids. $A = 2(lw + lh + wh)$ $V = l \times w \times h$

Walls Dividing the Inside and Outside Areas of the Mosque

The walls are decorated with porcelain plates which, according to local tradition, were a gift from the Chinese emperor to Sunan Gunung Jati on his marriage to Princess Ong Tien [18]. Hermana [18] interprets this decoration as showing that Islam is open to the cultural works of other peoples as long as they do not contradict Islamic teaching.

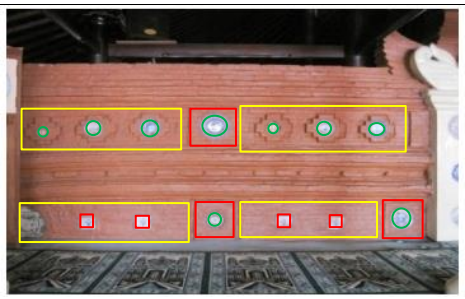
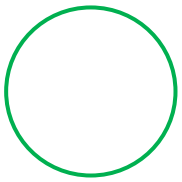
Table 4. Geometric shapes in the walls dividing the inner and outer areas of the mosque

Overview	Geometric Shapes	Remarks
	Square  Rectangle	• Square: a quadrilateral with four equal sides and four right angles; it forms the frames of individual plate panels. $A = s^2$ $P = 4s$ • Rectangle: a quadrilateral with four right angles whose opposite sides are equal

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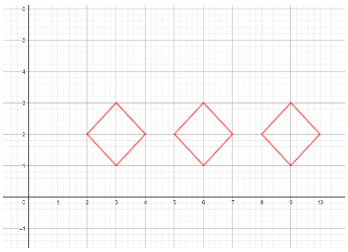
Overview	Geometric Shapes	Remarks
 Figure 4. Walls Dividing the Inner and Outer Areas of the Mosque	Circle 	and parallel; it forms the horizontal panels that hold rows of plates. $A = l \times w$ $P = 2(l + w)$ • Circle: the set of points at the same distance r from a centre; it is the outline of each porcelain plate. $A = \pi r^2$ $C = 2\pi r$

3.1.2. Geometric Transformations

Ventilation Openings

Hermana [18] describes the diamond-shaped ventilation openings as resembling a Portuguese cross ornament, which he attributes to the influence of Christian culture. He interprets the four arms of the motif as the four stages of human life (the realm of spirits, the womb, the world and the hereafter), the four elements that form human beings (earth, water, air and fire) and the four Sufi stages towards God (sharia, tariqa, haqiqa and ma'rifa), united in the principle of *ahwal* and *maqamat*.

Table 5. Translation in the ventilation openings

Overview	Geometric Shapes	Remarks
 Figure 5. Ventilation openings	Translation  Figure 6. Translation model of the ventilation openings	• The openings are repeated horizontally at equal intervals, so that each opening is the image of the previous one under a horizontal translation. • Each opening is modelled as a rhombus (a square rotated by 45°); shape and size are preserved, and the displacement is constant. • Translation: $(x', y') = (x + a, y + b)$. In the model (Figure 6), the opening centred at (3, 2) is mapped to (6, 2) and then to (9, 2), so a = 3 and b = 0: $T(3,0)$.

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Outer Mihrab

The mihrab is a niche in the qibla wall that indicates the direction of prayer and the position of the imam. Its design is interpreted as expressing one main message, the oneness of God and complete surrender to the Creator.

Table 6. Reflection in the outer mihrab

Overview	Geometric Shapes	Remarks
 Figure 7. Outer Mihrab	Reflection  Figure 8. Reflection axis of the outer mihrab	• The elements on the right of the central vertical axis correspond to those on the left at equal distances from the axis (yellow line in Figure 8). • The facade therefore shows approximate bilateral (mirror) symmetry; small differences, such as the patterns of individual plates, mean that the symmetry is structural rather than exact. • Reflection in the y-axis (vertical axis): $(x', y') = (-x, y)$

Mosque Gate (Kuta Kosod)

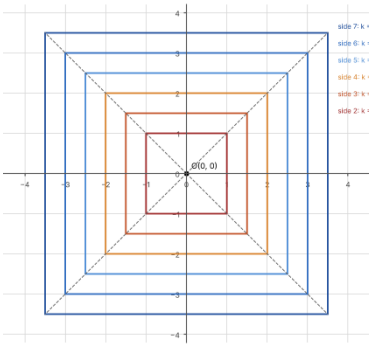
The *kuta kosod* (brick fence) around the mosque, with its split gate in the style of a *candi bentar*, shows the influence of Hindu architecture. Nurfadli [21] interprets the elements of the mosque, including the *kuta kosod*, as representing intercultural tolerance.

Table 7. Reflection and dilation in the kuta kosod

Overview	Geometric Shapes	Remarks
 Figure 9. Kuta kosod gate	Reflection  Figure 10. Reflection axis of the Kuta Kosod gate	• The two halves of the split gate have the same shape and are positioned symmetrically about the centreline of the gate (blue line in Figure 10). • Each point on one half corresponds to a point on the other half at the same distance from the

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Overview	Geometric Shapes	Remarks
		axis, so the gate shows bilateral symmetry. • Reflection in the vertical axis (y-axis): $(x', y') = (-x, y)$.
 Figure 11. Brick finial on the kuta kosod pillar	Dilation  Figure 12. Dilation model of the square tiers (plan view, arbitrary units)	• The brick finial on the gate pillar consists of square tiers that become smaller towards the top. • In plan (top view), the tiers are concentric squares, so each tier is the image of the lowest tier under a dilation centred at the common centre O with scale factor 0 < k < 1. In the model (Figure 12), side lengths 7, 6, 5, 4, 3 and 2 (arbitrary units) correspond to k = 1, 6/7, 5/7, 4/7, 3/7 and 2/7. Because the tiers have equal heights, the dilation describes the horizontal cross-sections rather than the elevation. • Dilation with centre P(a, b) and scale factor k maps A(x, y) to A′(x′, y′), where $x' = a + k(x - a)$ $y' = b + k(y - b)$.

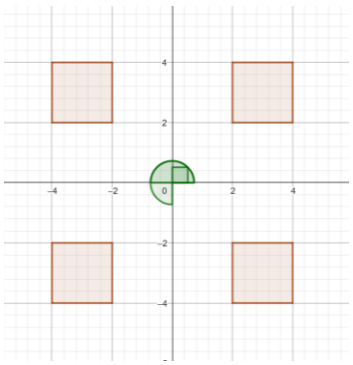
Wall Relief Ornaments

The relief on the wall of the mosque contains a symbol of the sun. As with the fence ornament, Hermana [18] interprets the sun as a symbol of the light of knowledge and spirituality that guides human beings towards faith and piety to Allah SWT.

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Table 8. Rotation in the wall relief ornaments

Overview	Geometric Shapes	Remarks
 Figure 13. Relief Ornaments	Rotation  Figure 14. Rotation model of the relief motif	• Each part of the motif has the same shape and size and lies at the same distance from the centre of rotation. • Rotating the motif about its centre through 90°, 180° or 270° maps it onto itself, so it has rotational symmetry of order 4. The motif is also approximately symmetric under reflection in four axes (horizontal, vertical and two diagonals), so its symmetry group is the dihedral group D4 [23]. Figure 14 shows the Figures of one unit under these counterclockwise rotations: • Rotation 90°: $A(x, y) \rightarrow A'(-y, x)$ Rotation 180°: $A(x, y) \rightarrow A'(-x, -y)$ Rotation 270°: $A(x, y) \rightarrow A'(y, -x)$

3.2. DISCUSSION

The ethnomathematical analysis of the Panjunan Red Mosque supports D'Ambrosio's view that mathematical ideas develop and are used in specific cultural contexts [3]. The geometric shapes and transformations found in the mosque are not merely decorative; they reflect how a past community organised a place of worship according to principles of order, balance and harmony. The symmetry and repetition observed here resemble those reported in other mosques and temples in Indonesia [6]–[8], [15], suggesting a shared regional design vocabulary across Islamic and Hindu-Buddhist traditions.

Unlike previous studies that identified geometric shapes separately, this study shows that the Panjunan Red Mosque combines several types of geometric transformation as integrated design principles. The three isometries—translation in the ventilation openings, reflection in the mihrab and gate, and rotation in the relief—produce congruent repetition

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and visual balance. In contrast, dilation in the tiered finials produces similar figures of decreasing size that create a sense of hierarchy and upward movement. The rotational symmetry of the relief can be described precisely by the dihedral group D4, which illustrates how symmetry-group classification [23] adds rigour to ethnomathematical description. The distinctiveness of the mosque lies in the integration of these transformations within an architecture that synthesises Javanese, Hindu-Buddhist, Chinese and Islamic traditions [18]–[21], so that geometry acts as a common visual language across cultural traditions.

These findings have practical implications for culture-based mathematics learning. Teachers can design worksheets in which students identify reflections and rotations in the gate, mihrab, and relief; determine the translation vector of the ventilation openings; model the dilation of the tiered finials in GeoGebra by choosing a centre and a scale factor; and connect the history of the Panjunan Red Mosque with the analysis of geometric concepts. Such activities allow students to learn mathematics in a contextual, visual and meaningful way, in line with an ethnomathematical approach that links mathematical concepts with students' cultural experiences [2], [3], [14], [15].

This study has several limitations. It is a qualitative descriptive study of a single site with one key informant, so its findings cannot be generalised widely. The geometric models are schematic: they were constructed from photographs in arbitrary units rather than from on-site measurements, so they describe the type of transformation but not the actual dimensions or proportions of the elements. In addition, the findings have not yet been applied or evaluated in classroom learning. Future research should measure the dimensions and proportions of the architectural elements, involve more informants, and test learning materials based on these findings in the classroom.

3.3 Learning Implications

Ethnomathematics can be implemented in mathematics learning by connecting mathematical concepts with local cultural elements [2], such as the architecture of the Panjunan Red Mosque as a product of cultural acculturation in the archipelago. The geometric shapes and transformations found in the ornaments, roof, pillars, and gate of the mosque can be developed into contextual and meaningful culture-based learning resources for students.

Teachers can use these results as a basis for modules or worksheets that use the architecture of the mosque as a context for learning plane geometry, solid geometry, and geometric transformations. This approach is in line with the Merdeka Curriculum, which emphasises contextual learning rooted in local wisdom [2]. Further research is needed to develop such materials and to test their effectiveness empirically.

4. CONCLUSION

This study shows that the architecture of the Panjunan Red Mosque embodies a coherent set of mathematical concepts. Plane figures—squares, rectangles, circles, triangles, trapezoids and rhombuses—appear in the fence ornaments, porcelain-decorated walls, roof elevations and ventilation openings, while the pillars and tiered roof take the form of cylinders, cuboids, a pyramid and a pyramid frustum. The building also uses all four basic

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geometric transformations: translation in the ventilation openings, reflection in the mihrab and the split gate, rotation in the wall relief, and dilation in the tiered brick finials. The isometries create congruent repetition and balance, whereas dilation creates gradation and hierarchy.

These mathematical regularities are interwoven with the philosophical and spiritual meanings attached to the building and with its blend of Javanese, Hindu-Buddhist, Chinese and Islamic traditions. Mathematics in the mosque is therefore not separate from community life but part of how aesthetic, spiritual and social values are expressed. The findings provide a basis for culture-based geometry learning and for science-based preservation of the mosque's heritage. Future work should measure the elements on site, include more informants, and test learning materials derived from these findings in the classroom.

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