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Journal of Teaching Mathematics, Social Research and Opinion
Vol. 5, No. 1, March 2026, pp. 651 – 664, https://doi.org/10.58421/misro.v5i1.588
ISSN 2962-7842

An Ethnomathematical Analysis of the At-Taqwa Mosque Minaret, Cirebon: Implications of Mathematics Learning

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Article Info

Article history:

Accepted 2025-07-06
Revision 2026-02-09
Accepted 2026-03-07

Keywords:

Contextual Learning
Ethnomathematics
Islamic Architecture
Symmetry
Tessellation

ABSTRACT

This research aims to address a research gap in the integration of mathematical concepts into Islamic architectural design by examining the tower of the At-Taqwa Mosque in Cirebon through an ethnomathematical lens. Using a descriptive qualitative approach, data is collected through field observations, visual documentation, and geometric shape analysis to identify the mathematical structures embedded in the mosque architecture. The results showed that the 65-meter-tall tower incorporates a variety of geometric elements, including a golden dome, a conical top, and an octagonal prism, symbolizing a spiritual ascent from the earthly to the divine. The octagonal shape serves as a transitional geometry between the square, representing the earth, and the circle, symbolizing the sky, reflecting the cosmological harmony in Islamic architecture. In addition, repetitive patterns such as squares, zig-zags, and rhombuses are closely related to cultural and religious values rooted in the Wali Songo tradition. The tower's vertical structure, which gradually narrows, can be modeled mathematically as a geometric sequence, symbolizing a spiritual elevation toward transcendence. Overall, architectural design embodies basic mathematical principles, including symmetry, tessellation, geometric transformation, and proportional reasoning. These findings suggest that integrating mosque architecture into mathematics instruction can increase cultural awareness, spatial reasoning skills, and appreciation for the interconnectedness among mathematics, art, and spirituality.

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1. INTRODUCTION

Mathematics plays an inseparable role in human life, although many still consider it a difficult and confusing subject [1]. However, mathematics is inherent in many aspects of life, including cultural heritage. The diverse cultures of Indonesia not only preserve aesthetic

and historical values but also contain mathematical principles embedded within them. The application of mathematics in culture supports calculation, problem-solving, and the preservation and development of cultural heritage, so that mathematics functions not only as a technical discipline but also as a cultural expression. However, public awareness of the relationship between mathematics and culture is still limited, so an approach is needed to bridge the two, one of which is ethnomathematics.

Etymologically, ethnomathematics consists of three main components: ethno, mathematics, and tic. The term ethno refers to the forms of mathematics that develop within a particular cultural community, including symbols, languages, cultural codes, folklore, and distinctive ways of thinking and reasoning [2]. The mathematical component includes measurement, classification, spatial and temporal reasoning, comparison, and quantitative processing, while tic deals with techniques and social codes that are received and transmitted through communication within a community [3]. This concept expands the understanding of mathematics by asserting that mathematical thinking is shaped by social and historical contexts, not solely by formal Western systems. This theoretical foundation has been reinforced by international scholars such as D'Ambrosio (1985), Gerdes (1996), Barton (1999), and Rosa and Orey (2016), who suggest that ethnomathematics can be a bridge between local knowledge, culture, and modern mathematics Education [8], [9].

In a global context, various studies have also shown that architecture is a rich medium for ethnomathematical exploration, especially in religious buildings that blend geometry, proportion, symmetry, and symbolic meaning. International research on Islamic architecture highlights the role of geometric patterns, transformations, and proportional ratios as expressions of mathematical knowledge integrated with spiritual and aesthetic values [5], [6]. In line with that, the Great Mosque of At-Taqwa in Cirebon serves not only as a center of worship but also as a symbol of the community's cultural identity. Its 65-meter-tall tower features geometric, symmetrical, and proportional characteristics that can be analyzed using concepts in spatial geometry, transformation, and symmetry. The elements of cylindrical shapes, cones, circular patterns, octagonal bases, and vertical constriction structures reflect the integration of mathematical reasoning, aesthetic meaning, and spiritual symbolism.

Previous studies have explored ethnomathematical aspects of mosque architecture, including research on the Great Mosque of At-Taqwa in Bondowoso [7]. However, the research primarily focuses on identifying basic geometric shapes for the development of learning media and has not examined in depth the symbolic and spiritual dimensions of architectural structures. In addition, the analysis of the tower as a major architectural element remains limited, and the theoretical framework used bears little relation to the findings of broader international studies.

To reinforce the direction of the research, this study aims to answer the following questions: (1) What mathematical principles and geometric shapes are embedded in the architecture of the tower of the At-Taqwa Mosque? (2) What is the symbolic and philosophical meaning associated with these mathematical elements? (3) How can these findings be used as a learning resource in contextual mathematics Education?

2. METHOD

This study uses a descriptive qualitative approach with an ethnomathematical perspective. This approach aims to explore and describe the mathematical concepts and philosophical meanings contained in the architecture of the At-Taqwa Grand Mosque Tower in Cirebon. The selection of research objects is based on the tower's status as a cultural heritage building with religious, historical, and architectural value.

In this study, the researcher acts as the main instrument (human instrument) that is directly involved in the process of data collection and analysis. Data were obtained through literature studies, field observations, and documentation. The literature study was conducted to strengthen the theoretical foundation of the research, which included the history and architecture of the Great Mosque of At-Taqwa, the ethnomathematical theories developed by D'Ambrosio, Rosa, and Orey, and previous research on the relationship between geometry and Islamic architecture.

Observations are carried out directly and systematically of the mosque tower's structure. Observations were focused on identifying geometric shapes, building proportions, and ornamental patterns at each tower level. During the observation process, the researcher made visual recordings, took photos, and made architectural sketches as supporting data for the analysis. Documentation complements observation data through visual recordings and field notes, which are then transformed into textual data.

Data analysis is carried out through several stages. The first stage is data reduction, selecting information relevant to the research objectives. At this stage, a coding process is used to identify emerging mathematical concepts, such as the shape of the building, symmetry, geometric transformations, and repetition patterns. The second stage is the presentation of data by grouping the code into thematic categories, such as spatial geometry, transformation geometry, and numerical symbolism. The third stage is data interpretation, in which mathematical concepts are associated with cultural meanings and spiritual values, informed by a literature review. The final stage is the systematic preparation of research findings into narrative descriptions, accompanied by visual documentation.

3. RESULTS AND DISCUSSION

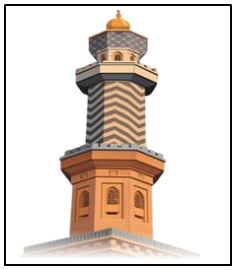
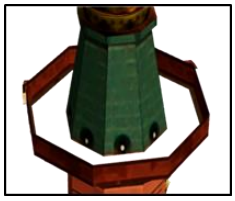
The study identified nine main ethnomathematical elements embedded in the architectural design of the tower at the At-Taqwa Grand Mosque in Cirebon: the general structure of the tower, its top, repetitive patterns, mihrab motifs, square patterns, zig-zag patterns, rhombus patterns, window arrangements, and octagonal floor levels.

3.1. Results

Based on data collected through literature reviews, field observations, and documentation, several key ethnomathematical elements were identified in the tower of the At-Taqwa Grand Mosque in Cirebon. The tower shows a vertical structure about 65 meters high, tapering towards the top. This progressive narrowing can be modeled as a descending geometric sequence, reflecting a symbolic spiritual ascension. The vertical orientation reflects the intrinsic relationship between mathematical forms and religious symbolism in Islamic architecture [10].

The top of the tower is composed of three main geometric shapes, each with a different symbolic meaning. The hemispherical golden dome symbolizes divine unity and perfection. The cone, pointing upward, symbolizes the spiritual ascension to the divine. Meanwhile, the octagonal prism serves as a transitional form, philosophically describing the transition from the material world to the spiritual realm.

Table 1. The geometric shape of the mosque tower was identified

Figure	Information
 Figure 1. The At-Taqwa Grand Mosque Tower in Cirebon	• The tower is about 65 meters high and tapering upwards. • The vertical shape reflects the mathematical structure and symbolism of Islam.
 Figure 2. Hemispherical dome at the top of the tower	• The dome is geometrically a hemisphere. • This shape symbolizes unity and perfection.
 Figure 3. Conical structure supported by an octagonal prism	• The structure is conical with a circular base and a single peak. • The upward orientation emphasizes the vertical direction.
 Figure 4. Conical structure supported by an octagonal prism.	• A regular octagonal prism supports the cone. • The octagon serves as a transitional geometric shape.

The repetitive pattern is the defining characteristic of the tower's ornaments, which consist of geometric motifs such as squares, zig-zags, and rhombuses, arranged

symmetrically and systematically. These iterations reflect basic mathematical principles, including symmetry, rotation, reflection, translation, and tessellation. For example, a zig-zag pattern is vertically aligned, depicting geometric transformations through translation and reflection symmetry. The rhombus shape is commonly found in carvings and is characterized by two lines of reflective symmetry and second-order rotational symmetry [11]. In addition, nine square motifs surround the tower's balcony in a balanced configuration, symbolizing Wali Songo, nine revered figures who played a central role in the spread of Islam throughout Java [12].

Table 2. The geometric shape of the mosque tower was identified

Figure	Description
 Figure 5. Zig-zag ornamental pattern on tower walls	• The zig-zag motif appears repeatedly along the walls of the minaret. • This pattern describes translation and reflection.
 Figure 6. Rhombus motif in tower ornament	• The rhombus motif has reflective symmetry and rotational symmetry. • The pattern shows the symmetry of a two-order rotation.
 Figure 7. Square motif on tower balcony	• Square motifs are arranged symmetrically around the balcony. • Nine squares symbolize Wali Songo.

The three-pointed, arched mihrab pattern resembles a parabola and represents the pillars of Islam: Islam, Faith, and Ihsan.

Table 3. The geometric shape of the mosque tower was identified

Figure	Description
 Figure 8. The part of the tower that contains the mihrab pattern	• It consists of three pointed arches. • The arch resembles a parabola and embodies Islamic principles.

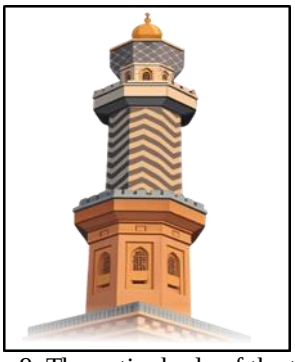
The arched tower windows are placed symmetrically and contribute to radial symmetry, while the plan transitions from square to octagonal at the top, symbolizing the movement from the physical world to the spiritual realm. Research by Baydoun and Sapian [reference] emphasizes that this repeating pattern is not only aesthetically pleasing but also improves the quality of interior ventilation [13].

Table 4. The geometric shape of the mosque tower was identified

Image	Description
 Figure 9. Tower windows	• Curved windows are arranged symmetrically. • The arrangement forms radial symmetry.

On the top floor, the floor plan transitions from square to octagonal. The octagon serves as a symbolic link between the material world and the spiritual domain, acting as a geometric bridge between the earthly square and the celestial circle in Islamic architectural philosophy.

Table 5. General view of the mosque tower

Figure	Description
 Figure 9. The entire body of the tower	• The main body of the tower tapered upwards. • It symbolizes spiritual ascension and reflects cultural and mathematical values.

These findings suggest that the ethnomathematical features of the tower of the Grand Mosque of At-Taqwa are not only decorative but carry profound mathematical and spiritual significance. The intuitive application of geometric shapes and repetitive patterns illustrates a deep cultural understanding of mathematical concepts, developed outside the realm of formal Education.

3.2. Discussion

3.2.1 Interpretation of Geometric Symbolism

The very top of the mosque tower is decorated with a magnificent golden dome. Below it is a conical structure, supported by an octagonal prism that serves as the main foundation. This series of geometric shapes is not only the result of architectural creativity, but rather reflects the depth of mathematical and cosmological thinking that has long been internalized in local culture. The combination of domes (hemispheres), cones, and octagonal prisms signifies a local understanding of vertical spatial composition and spiritual orientation toward the Divine.

Figure 10. Great Dome

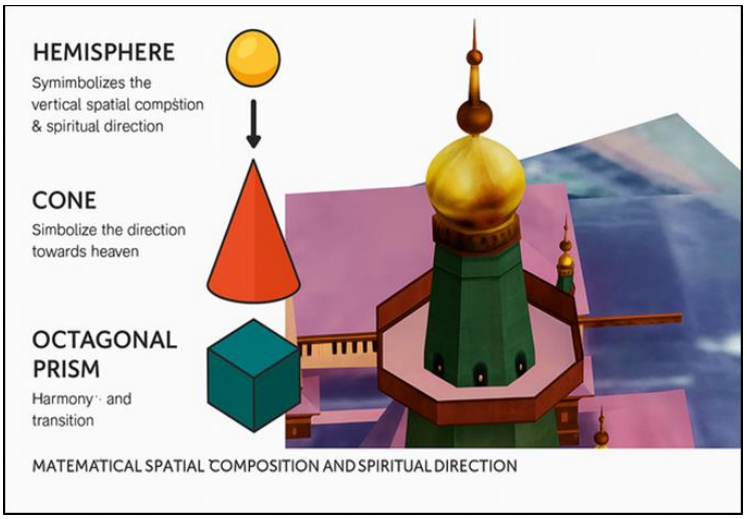


Figure 11. Tower Parts

The Dome Alone symbolizes the universe of the sky and the wholeness of God's perfection and oneness [14]. In geometry, a dome is often modeled as a half-sphere (hemisphere), so the volume and surface area can be calculated by multiplying the formulas for a sphere by 2. The formula can calculate the volume of the dome (V): While the wide surface dome (without base) (A) [15] is:

$$V = ½ \times \frac{4}{3} \times \pi \times r^3 = \frac{2}{3} \times \pi \times r^3 . A = 2 \times \pi \times r^2$$

Below the dome, a cone tapering upwards depicts the vertical direction from the earth to the sky. In mathematics, a cone is a geometric shape. rooms with a circular base and a single point top. This definition was officially applied by Mathar [16], who modeled a "solid right circular cone with a peak at the origin and a circular base" in his study of the cone-sphere volume intersection. Similarly, Frego and Consonni [17] investigate the beveled and right cones, emphasizing their geometric properties and volume-preserving transformations while maintaining the basic cone structure with a single peak and a circular or elliptical base. The formula can calculate the volume of a cone (V):

$$V = \frac{1}{3} \times \pi \times r^2 \times t$$

where r is the radius of the base and t is the height of the cone. The shape of this cone is philosophical, reflecting the narrowing of man's spiritual journey to its highest point of consciousness: monotheism.

Meanwhile, the shape of the eight aspects (octagon) serves as a symbolic link between the circle (sky) and the square (earth), depicting the harmony and transition between material and spiritual properties in Islamic architecture. In geometry, the aspect area of a regular octagon can be calculated by the formula: where s is the long side. This shape has 8 symmetries. 45° folding rotation and symmetry, which make it ideal for the repetition of design patterns (tessellation) such as floor tile patterns, windows, and ornamental buildings. This combination of aesthetic, spiritual, and mathematical values demonstrates the depth of understanding of geometry in the Islamic architectural tradition.

$$L = 2 \times (1 + \sqrt{2}) \times s^2$$

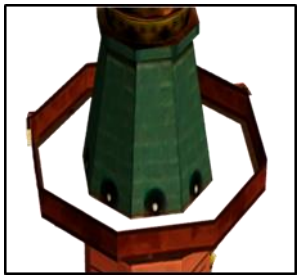


Figure 12. Octahedron

Figure 13. Octagonal prism

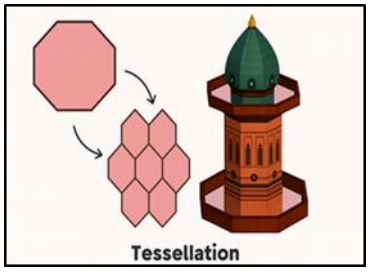


Figure 14. Tessellation

In addition, aspect eight has a symmetrical center of rotation at 45°, which means the can pattern is played at 45°, 90°, 135°, and 360°, and it constantly occupies the same position. This symmetry reinforces the visual regularity and rhythmic structure of the geometric patterns used in architectural towers. The combination of these three transformations, folding and rotating symmetry, forms a complex yet harmonious tessellation pattern, reflective order and beauty, mathematically harmonious with the values of aesthetics and spirituality in Islamic architecture. The regular shape of the eight has 8-fold consistent fold symmetry, making this structure not only functional but also aesthetically and mathematically appealing.

3.2.2 Mathematical Analysis of Ornament Patterns

Zig-zag pattern

Figure 15. Zig-zag pattern

The repetitive patterns on the tower body reflect the principles of symmetry, transformation (rotation, translation, reflection), and structural fractals [18]. For example, in

symmetrical reflection, the pattern ornaments on the left- and right-hand sides can be analyzed using axis symmetry, where each point on one side has a reflection of its pair point on the other. In mathematics, reflection on the x or y axis is expressed by the formula: reflection on the x-axis and reflection on the y-axis: (x, y) → (-x, y). For translational transformations, which are the regular repetition of motifs in a horizontal or vertical direction, it can be explained by the formula: where a and b indicate the displacement of units a to the right and units b upwards. The rotation principle is also evident in pattern ornaments that rotate around a central point. The rotation of θ degrees to the point of origin is formulated by [19].:

$$(x, y) \rightarrow (x, -y)$$
$$(x, y) \rightarrow (x + a, y + b)$$
$$(x, y) \rightarrow (x \cos\theta - y \sin\theta, x \sin\theta + y \cos\theta)$$

In addition, geometric structures such as octagonal prisms arranged in tiers reflect fractal patterns, i.e., the repetition of similar shapes at different scales [20]. This fractal concept can be explained mathematically using recursive formulas, such as f(n) = f(n-1) + r, where f(n) is the scale of the form at the nth level, and r is the reduction ratio. In ethnomathematics, the application of these concepts shows that mathematical values naturally live in society's culture. Mathematics is not limited to formal Education, but it comes through everyday practice and cultural heritage that has evolved from generation to generation $S = r \times S_{-1}, S$[21].

The tower also features various geometric ornaments, such as pattern boxes, rhombus motifs, and zig-zag patterns, arranged in a symmetrical, circular pattern. The zig-zag motif repeats on the sides. Aspect eight shows the geometry of the implementation draft transformation, i.e., the vertical translation, the symmetrical fold, and the symmetrical center of rotation. In mathematics, translation can be expressed by the formula:

$$T(x, y) \rightarrow (x, y + k)$$

where *k* is the shift in vertical distance.

This indicates that each element of the zig-zag pattern shifts to one in a manner consistent with the remaining distance, creating rhythmic, regular repetition. In addition to translation, the pattern also shows the presence of symmetrical folds on the sides of the regular eight, which have an 8-axis symmetry, that is, the line that divides the shape into two identical parts. This means that each side of the eight aspects reflects a symmetrical zig-zag pattern to the center and to the fold line.

Square Pattern

Figure 16. Square Pattern

A series of nine square patterns surrounds the tower's balcony in a symmetrical configuration. In general, the number 9 is often associated with ornamental towers that

symbolize Wali Songo, the nine guardians of the spread of Islam in Java, as a representation of spiritual perfection. In the decimal system, the number 9 is the peak before returning to 0, symbolizing the highest spiritual completion before a new phase begins. A study by Yosef [22] highlights that the number 9 in the Ethiopian Orthodox Tewahedo Church is used in spiritual practice at the ninth hour and is considered a symbol of divine finality and transcendent preparation.

The pointed arch, resembling a mihrab on a wall tower, can be modeled as a parabolic curve or a pointed arch in geometry, symbolizing the direction of the Qibla and the spiritual center of Muslims.

Rhombus Pattern

Figure 17. Rhombus Pattern

The rhombus pattern, composed of two isosceles triangles facing the direction of the foot, reinforces the design's visual and mathematical value. The shape of this four-sided figure is characterized by straight lines of the same length, two perpendicular diagonals that split in two, as well as two folding and rotating symmetries [23]. This pattern is often used in tessellation and introduces comparison of drafts and widths in learning mathematics.

Mihrob pattern

Figure 18. Mihrob pattern

The three recurring arches found in the mihrab pattern not only serve as decorative elements but also carry deep religious and philosophical meanings. In Islamic teachings, this triadic pattern symbolizes the three basic pillars of faith: Islam (submission), Iman (trust), and Ihsan (spiritual excellence). Such three-tiered structures have long been embedded in traditional mosque architecture—especially during the Walisanga era—as a representation of a Muslim's spiritual journey [24]. As noted by Nurdin and Hidayat [25], this layer of architecture reflects the progression from outward practice (Islam) to internal belief (Iman) and, finally, to the highest spiritual consciousness (Ihsan).

Figure 19. Tower windows

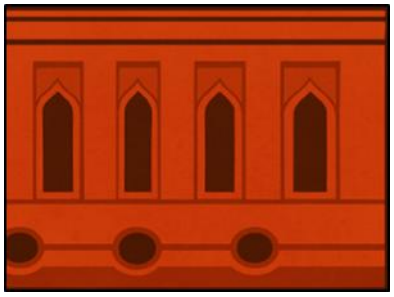


Figure 20. Motifs on the Tower windows

The windows that surround the sides of the tower also feature circular patterns and ornamental repetition shapes, emphasizing consistency using the eight aspects from the base to the top of the tower. On the balcony of a fence or ornamental wall, the symmetrical pattern and geometric base reinforce the building's visual stability.

3.2.3 Linkages to Culture and Religious Values

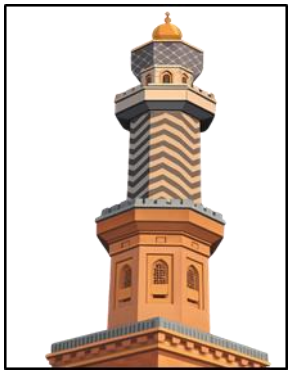


Figure 21. Mosque tower

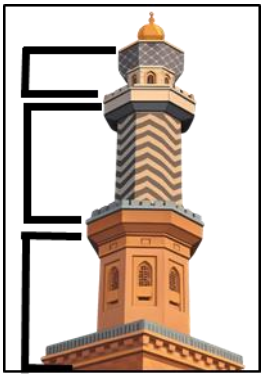


Figure 22. Tower Support Distance

From an ethnomathematical perspective, the form serves as a strong support for the more complex, in both structural and spiritual ways. The tower on the upper floor changes its shape into an eighth aspect, which in Islam and Javanese culture, symbolizes the direction of the complete wind, the balance of the cosmos, and the presence of 8 angels who hold the throne of God (QS. Al-Haqqah: 17). In ethnomathematics, the change of form from a rectangle to an aspect of the eight is a representation of the spiritual transition from the physical world to the natural Divine. Structurally, the cross-section of the tower that is getting higher and lower can also be modeled as a series of geometries downwards, with n as the height of the floor and r as the size ratio, which symbolizes structural efficiency and humility in approaching God.

$$h = h_1 \cdot r^{n-1}, h$$

Thus, the entire structure and ornamental tower serve not only as aesthetic and architectural elements, but also as reflections of the values of mathematics, spirituality, and culture, uniting the local in physical form. The mosque tower not only rises vertically but also represents man's journey from the world to divinity, from form to meaning, from building to sign.

3.2.4 Implications for Math Learning

The study's results show that the architecture of the mosque tower can serve as a context for mathematics learning. The concepts of building space, transformation geometry, and number patterns can be taught through the exploration of local cultural objects.

This approach can help improve students' understanding of geometry concepts, spatial reasoning skills, and cultural awareness. The use of real objects in learning can also increase motivation by allowing students to relate mathematical concepts to their surroundings.

3.2.5 Limitations and Advanced Research

This research has several limitations. The research uses a qualitative approach, so the results are descriptive and cannot be generalized widely. In addition, the research focuses on only one cultural object: the tower of the Great Mosque of At-Taqwa.

Further research can expand the study by comparing various mosque architectures in other areas. Future research can also develop ethnomathematics-based learning media and test their effectiveness on students' mathematics learning outcomes.

4. CONCLUSIONS AND SUGGESTIONS

This study concludes that the architecture of the tower of the Great Mosque of At-Taqwa in Cirebon is a manifestation of integration between mathematical concepts and Islamic cultural values. Through an ethnomathematical approach, this study identifies geometric principles, such as the shapes of domes, cones, and octagonal prisms, as well as repetitive ornamental patterns that reflect symmetry, transformations (rotation, translation, reflection), tessellation, and proportional reasoning. These findings suggest that the tower's structure not only serves aesthetic and structural purposes but also carries symbolic meanings that represent a spiritual journey from the mundane to the transcendental.

The main contribution of this research lies in two aspects. First, this study deepens the ethnomathematical understanding of the tower of the At-Taqwa Mosque as a cultural artifact that integrates geometry, symbolism, and spirituality. Second, this study provides significant pedagogical implications for the development of contextual and culturally responsive mathematics learning, particularly in the teaching of geometry through real cultural contexts.

Ultimately, this study shows that the tower of At-Taqwa is not just a physical structure but a sophisticated cultural-mathematical text that offers a meaningful pedagogical bridge between the world of abstract geometry and the spiritual heritage of a community.

The findings of this research can be used practically in the design of ethnomathematics-based mathematics learning modules that integrate local architectural heritage as learning resources. In addition, the development of digital ethnomathematics resources, such as interactive three-dimensional models or virtual tours of Islamic architecture, is recommended to enhance students' spatial reasoning, cultural awareness, and appreciation of mathematical wisdom embedded in local traditions.

Further research is suggested to expand the study of ethnomathematics to other cultural artifacts across various regions of Indonesia and to use a multidisciplinary approach that combines mathematics, architecture, anthropology, and cultural studies to enrich scientific treasures and preserve mathematical cultural heritage.

ACKNOWLEDGEMENTS

The author greatly appreciates the contribution and support provided by all individuals and institutions involved in this research. Special recognition is given to academic advisors and peers whose guidance, constructive advice, and ongoing encouragement played a crucial role in completing this research. The success of this research would not have been possible without the cooperation and assistance of all those who participated directly or indirectly.

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