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Multidimensional Analysis in the Development of Augmented Reality-Based Digital Ethnomathematics Module: A Case Study at Keraton Kasepuhan Cirebon

Dian Anggraeni Maharbid[1], Tatang Herman[2*], Mubiar Agustin[3], Cepi Riyana[4], Ejen Jenal Mutaqin[5]

[1,2*,3,4,5]Mathematics Education, Universitas Pendidikan Indonesia
Jalan Dr. Setiabudhi No. 229, Bandung, West Java, Indonesia
[2*]tatangherman@upi.edu; [3]mubiar@upi.edu; [4]cepi@upi.edu; [5]jenal86mutaqin@upi.edu

[1]Mathematics Education, Universitas Bhayangkara Jakarta Raya
Jalan Harsono RM No. 67, Ragunan, Pasar Minggu, South Jakarta, Indonesia
[1]dian.anggraeni@dsn.ubharajaya.ac.id

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Abstrak

Penelitian ini bertujuan menganalisis pengembangan modul digital etnomatematika berbasis augmented reality (AR) melalui sebuah pendekatan analisis multidimensional yang komprehensif. Penelitian menggunakan metode Research and Development (R&D) dengan model ADDIE. Data dikumpulkan melalui kuesioner terhadap 23 responden yang terdiri dari 13 guru dan 10 siswa, observasi langsung, dan wawancara mendalam. Kebaruan penelitian ini terletak pada pengembangan kerangka analisis multidimensional yang mengintegrasikan teori Technology Acceptance Model (TAM), teori perkembangan kognitif Piaget, dan perspektif etnomatematika D'Ambrosio untuk validasi kebutuhan pengembangan media pembelajaran inovatif. Hasil penelitian menunjukkan bahwa dari 13 bangunan di Keraton Kasepuhan, teridentifikasi 84 bangun ruang dan berbagai bangun datar yang dapat diintegrasikan dalam pembelajaran geometri. Sebanyak 100% guru menyatakan media berbasis AR dapat meningkatkan keterlibatan siswa, sementara 90% siswa menunjukkan antusiasme tinggi terhadap pembelajaran berbasis budaya lokal. Implikasi teoretis penelitian ini berkontribusi pada pengembangan kerangka konseptual integrasi teknologi-budaya dalam pendidikan matematika, sedangkan implikasi praktis menyediakan landasan empiris sebagai cetak biru (blueprint) untuk pengembangan media pembelajaran yang kontekstual dan bermakna.
Kata Kunci*: Augmented Reality; Etnomatematika; Geometri; Media Ajar; Modul Digital.*

Abstract

This study aims to analyze the development of an augmented reality (AR)-based digital ethnomathematics module through a comprehensive multidimensional analysis approach. The research employs Research and Development (R&D) methodology with the ADDIE model. Data were collected through questionnaires administered to 23 respondents (13 teachers and 10 students), direct observations, and in-depth interviews. The novelty of this research lies in the development of a multidimensional analysis framework that integrates the Technology Acceptance Model (TAM), Piaget's cognitive development theory, and D'Ambrosio's ethnomathematics perspective to validate the need for innovative learning media development. The findings reveal that among 13 buildings in Keraton Kasepuhan, 84 solid figures and various plane figures were identified for integration into geometry learning. All teachers (100%) agreed that AR-based media could enhance student engagement, while 90% of students demonstrated high enthusiasm for culturally-based learning. The theoretical implications contribute to the conceptual framework development for technology-culture integration in mathematics education, while practical implications provide an empirical foundation that serves as a blueprint for developing contextual and meaningful learning media.
Keywords: Augmented Reality; Ethnomathematics; Geometry; Teaching Media; Digital Module.

I. INTRODUCTION

Mathematics serves as a fundamental discipline that cultivates essential 21st-century competencies, including logical, critical, analytical, and creative thinking (Dwi et al., 2022; Prayudho, 2024). As emphasized by Siswondo & Agustina (2021), mathematics provides transferable skills applicable across diverse real-world contexts. However, a persistent challenge in mathematics education lies in students' perception of the subject as abstract and disconnected from their daily experiences (Trisnani, 2022). This disconnect is empirically substantiated by Indonesia's 2022 PISA results, which revealed an average mathematics score of 366—significantly below the OECD average of 472 (OECD, 2023). These findings underscore the urgent need for pedagogical innovations that bridge the gap between abstract mathematical concepts and students' lived experiences.

Contextual learning approaches offer promising solutions to these challenges. Research by Sadiyah et al. (2023) dan Thahir & Suhaimi (2023), demonstrates that contextual learning significantly enhances student motivation and conceptual understanding by establishing meaningful connections between academic content and real-life situations. Among various contextual approaches, ethnomathematics emerges as a particularly powerful framework for mathematics education innovation.

Ethnomathematics, as theorized by D'Ambrosio (2001), represents an interdisciplinary field that examines the relationship between mathematics and culture. The term encompasses the mathematical practices, ideas, and procedures developed by identifiable cultural groups in response to their environmental, social, and cultural needs. This theoretical perspective challenges the universalist view of mathematics by recognizing that mathematical knowledge is culturally constructed and situated. In educational contexts, ethnomathematics provides a framework for making mathematics more accessible, relevant, and meaningful to diverse student populations by connecting formal mathematical content with students' cultural backgrounds and experiences.

Ethnomathematics, as conceptualized by D'Ambrosio (2001), recognizes and values the mathematical practices embedded within cultural contexts, thereby bridging formal mathematics education with cultural heritage (Dhiki & Bantas, 2021). Indonesia's rich cultural diversity provides an invaluable foundation for contextualizing mathematics learning, fostering both deeper conceptual understanding and cultural appreciation (Maharbid et al., 2025)(Syifa & Maharbid, 2025).

Concurrently, advances in digital technology present significant opportunities for educational enhancement (Said, 2023). Augmented Reality (AR), which integrates virtual objects into real-world environments as explained by Mamluatul Husnia & Wibisono (2022), has demonstrated particular promise in making abstract concepts tangible and accessible. Augmented Reality (AR) technology overlays digital content onto the physical environment, creating hybrid experiences that enhance

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perception and interaction with real-world objects. In mathematics education, AR offers unique affordances for visualizing abstract concepts, particularly in geometry where spatial reasoning is essential. In educational AR applications, these factors are mediated by instructional design quality, content relevance, and alignment with learning objectives.

The selection of Augmented Reality as the technological medium for exploring Keraton Kasepuhan's mathematical heritage is particularly justified from a cultural conservation perspective. Historical buildings such as the Kasepuhan Palace are protected cultural artifacts that cannot be physically manipulated, dissected, or modified for educational purposes. AR technology addresses this constraint by enabling students to visualize the "hidden sides" of architectural structures—such as geometric frameworks, cross-sections, and three-dimensional nets—without any physical contact with the heritage site. Students can virtually "unfold" the geometric structures of ancient roofs, examine the symmetrical principles underlying ornamental designs, and measure architectural proportions through digital overlays, all while preserving the physical integrity of these irreplaceable cultural treasures (Bekele et al., 2018; Ioannides et al., 2017). This non-invasive approach aligns with UNESCO's principles of heritage preservation while simultaneously maximizing educational accessibility and engagement.

The integration of AR with ethnomathematics creates a powerful synergy that can simultaneously strengthen mathematical understanding and stimulate students' curiosity and interest in learning (Rifai & Harsanto, 2023). Research indicates that this integration effectively enhances conceptual understanding, analytical skills, memory retention, and learning motivation (Aini & Indrawati, 2024; Anggeraini, 2023; Muharram & Susanti, 2024)

Keraton Kasepuhan Cirebon represents an exemplary cultural heritage site for AR-based ethnomathematics learning. The palace's ornamental and architectural elements embody diverse geometric concepts, from plane figures such as squares and trapezoids to solid figures including pyramids and prisms (Sofhya & Az-zahwa, 2024). Despite this significant educational potential, the integration of AR technology with Keraton Kasepuhan's cultural heritage in mathematics education remains substantially underexplored.

Previous studies on AR-based ethnomathematics learning have predominantly focused on development and validation outcomes (Hayati & Salsabila, 2023; Khasanah et al., 2024; Umri et al., 2025), with limited attention to comprehensive pre-development analysis. This gap is significant because effective educational technology development requires systematic assessment of multiple interconnected dimensions, including learner characteristics, curricular alignment, technological readiness, and cultural authenticity. The absence of a robust multidimensional analysis framework undermines the theoretical foundation necessary for developing contextually appropriate and pedagogically sound learning media.

This study addresses this gap by proposing and implementing a multidimensional analysis framework that integrates theoretical perspectives from the Technology Acceptance Model (TAM), Piaget's cognitive development theory, and D'Ambrosio's ethnomathematics framework. The novelty of this research lies in: (1) the development of an integrated analytical framework that systematically examines needs, learner characteristics, curriculum, and cultural context as interconnected dimensions; (2) the empirical validation of this framework through a case study at Keraton Kasepuhan Cirebon; and (3) the provision of a replicable methodological approach for future ethnomathematics-based learning media development.

Based on these considerations, this study was conducted with the aim of developing an innovative learning module and analyzing its quality and appropriateness through multidimensional analysis, ensuring that the resulting product is engaging, meaningful, culturally authentic, and contributes to both mathematical understanding and local cultural preservation.

II. Method

This study uses a Research and Development (R&D) approach, which aims to develop a product and evaluate its viability (Sugiyono, 2022). The product being developed is an augmented reality based ethnomathematics teaching module.

The development model chosen is the ADDIE model. According to Branch (2009), a visual representation of the ADDIE stages can be seen in Figure 1.

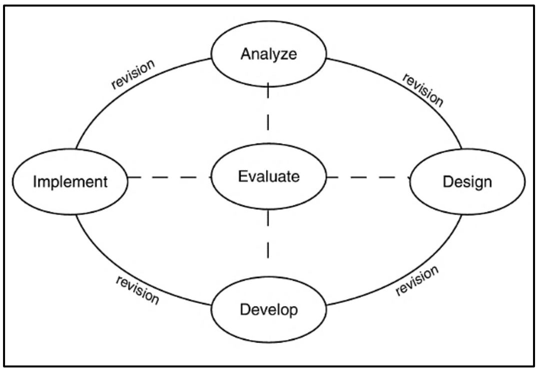

Figure 1. ADDIE stages (Branch, 2009).

Based on Figure 1, the ADDIE model consists of five stages: analysis, design, development, implementation, and evaluation.

It is important to emphasize that this paper specifically and exclusively focuses on the Analysis stage of the ADDIE model. This deliberate scope limitation is methodologically justified because the Analysis stage constitutes the foundational phase that determines the quality and relevance of subsequent development phases. Unlike studies that report complete development cycles with product trials and effectiveness testing, this research aims to establish a comprehensive, theoretically-grounded foundation through multidimensional analysis. The findings presented herein serve as prerequisite data for the Design and Development stages, which will be reported in subsequent publications. This approach aligns with the modular reporting practice in educational R&D research, where each ADDIE phase can constitute a distinct scholarly contribution (Aldoobie, 2015; Branch, 2009).

In this stage, researchers will conduct a comprehensive analysis of several aspects, including needs analysis, student character

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analysis, curriculum and materials analysis, and cultural context analysis.

Participants included 13 teachers and 10 students from five elementary schools in Cirebon Regency (n=23 for needs analysis) and 93 students from grades IV and V (for learner characteristics analysis). The cultural context analysis was conducted at Keraton Kasepuhan Cirebon on September 4, 2024, involving direct observation of 13 palace buildings and structured interviews with a palace servant (abdi dalem).

Data were collected through: (1) structured questionnaires assessing current learning conditions, technology accessibility, and cultural awareness; (2) observation protocols for documenting geometric elements in palace architecture; (3) semi-structured interview guides for gathering cultural and historical information; and (4) document analysis of curriculum standards. The instruments were designed to capture information relevant to each dimension of the multidimensional analysis framework.

Quantitative data from questionnaires were analyzed using descriptive statistics (frequencies and percentages). Qualitative data from observations and interviews were analyzed using thematic analysis to identify geometric elements and cultural contexts. The findings from all dimensions were synthesized to produce comprehensive development recommendations

III. RESULT AND DISCUSSION

A. Result

This section presents a descriptive statistical analysis of several aspects, including needs analysis, student character analysis, curriculum and materials analysis, and cultural context analysis.

Needs Analysis

A needs analysis was conducted to determine the differences between the current and desired situation in mathematics learning in elementary schools. Observations of the teaching and learning process, interviews with students and teachers, and a needs analysis questionnaire were conducted to obtain the necessary data.

The questionnaire was completed by 23 respondents from five elementary schools in Cirebon Regency. Data regarding needs analysis respondents can be seen in Table 1.

Table 1.
Needs Analysis Respondent Profile

No	Respondent Category	Number	Precentage
1.	Teachers	13	56%
2.	Students	10	44%
	Total	23	100%

Based on Table 1, it can be seen that the 23 respondents consisted of 13 teachers and 10 students. In more detail, the results of each questionnaire completed by teachers and students are presented in Table 2 and Table 3.

Table 2.
Needs Analysis Results: Teacher Perspective

No	Aspect	Results	Percentage
1	Students' difficulties in geometry	The majority of teachers stated that the geometry material in textbooks is still difficult for students to understand, especially the concepts of solid	76,9%

No	Aspect	Results	Percentage
		figures and the application of formulas.	
2	Availability of technology-based learning media	Most of teachers have not widely used digital media or augmented reality in mathematics learning	76,9%
3	Integration of local culture in mathematics learning	The majority of teachers have never linked geometry learning to the context of the Kasepuhan Palace Cirebon	76,9%
4	Student motivation to learn mathematics	Teachers stated that students were more enthusiastic and motivated when learning was linked to local culture.	92,3%
5	Use of AR in Learning	All teachers agreed that technology-based media such as augmented reality could increase student engagement and understanding in geometry learning	100%

Based on Table 2, it can be identified that 76.9% of teachers stated that the geometry material in textbooks is still difficult for students to understand, especially the concepts of solid figures and the application of formulas. As many as 76.9% of teachers also do not use technology much in learning, including augmented reality technology. In terms of integrating material with local culture, 76.9% of teachers have not linked the geometry material with the Kasepuhan Palace of Cirebon. Student motivation to learn mathematics shows a percentage of 92.3%, with teachers stating that students are enthusiastic and motivated when learning is linked to local culture. Furthermore, regarding the use of AR in learning, 100% of teachers agree that technology-based media such as AR can increase student engagement and understanding in geometry learning.

Meanwhile, from the students' perspective, the results of the needs analysis are presented in Table 3.

Table 3.
Needs Analysis Results: Student Perspective

No	Aspect	Results	Percentage
1	Perception of Mathematics	Some students enjoy mathematics, especially if they understand the concepts, but others experience difficulties and lack confidence.	50%
2	Difficulties in Geometry	Students' main difficulties are memorizing geometric formulas and understanding abstract concepts of geometric shapes	60%
3	Smartphone/Tablet Ownership	The majority of students have access to a smartphone or tablet that can be used for learning purposes.	80%
4	Experience Using AR Applications	Most of students have never used an augmented reality application for learning mathematics or other subjects.	70%
5	Knowledge of the Kasepuhan Palace	The majority of students are aware of the existence of the Kasepuhan Palace in Cirebon, but most of them have never	80%

No	Aspect	Results	Percentage
		visited or studied it in depth.	
6	Interest in Learning with Local Cultural Context	Almost all students are interested and enthusiastic when mathematics learning is linked to local culture, such as the architecture and ornaments of the Kasepuhan Palace in Cirebon.	90%

Based on Table 3, the results obtained from the needs analysis based on the student perspective are: (1) as many as 50% of students enjoy mathematics when they understand the concept; (2) as many as 60% of students experience difficulties in geometry material, especially in memorizing formulas and understanding the concept of geometric shapes abstractly; (3) 80% of students have access to smartphones or tablets to support learning purposes; (4) 70% of students have never used AR as a learning media for mathematics or other subjects; (5) 80% of students already know the existence of the Kasepuhan Palace in Cirebon but have never visited or studied it in depth; (6) 90% of students are enthusiastic if mathematics learning is linked to the local cultural context.

Based on the results of the needs analysis through questionnaires from the perspective of teachers and students, the results of the synthesis of the needs analysis can be presented in Table 4.

Table 4.
Synthesis of Needs Analysis

No	Aspect	Current Situation	Needs
1	Geometry Material	Abstract and difficult for students; challenges with formulas and spatial figures	More contextual geometry material, linked to students' environment
2	Learning Media	Dominated by textbooks and worksheets; limited digital and AR usage	Innovative technology-based media for concrete visualization
3	Cultural Integration	Teachers have not integrated Keraton Kasepuhan into geometry learning	Geometry learning with local cultural elements to increase enthusiasm
4	Student Interest	High interest in technology and culture, but not facilitated with appropriate media	Digital modules combining AR technology with cultural context

Based on Table 4, it can be seen that this needs analysis produces several needs that can be used as a reference for module development, including (1) the need for geometry material that is more contextual and connected to the students' environment; (2) innovative technology-based media that can visualize geometry concepts concretely; (3) the need for geometry learning that is integrated with local cultural elements; and (4) the need for digital modules that combine AR technology with culture.

Student Characteristics Analysis

To identify the target user profile for the AR-based ethnomathematics digital module, students' characteristics analysis must be conducted. According to Piaget's theory of cognitive development, the concrete operational stage occurs between the ages of 9 and 11, equivalent to elementary school students in grades 4 and 5. At this stage, students can learn more effectively by manipulating real objects and viewing visual images.

Demographic characteristics of students are presented in Table 5.

Table 5.
Demographic Characteristics of Students

No	Characteristics	Category	Number	Percentage
1.	Gender	Male	34	37%
		Female	59	63%
2.	Grade	IV	48	51%
		V	45	49%
3.	Age	9 years old	42	45%
		10 years old	43	46%
		11 years old	8	9%

Based on Table 5, it was found that there were 34 male students, or 37% of the total number of students. While there were 59 female students, or 63% of the total number of students. These students consist of 48 or 51% of 4th grade students and 45 or 49% of 5th grade students. Based on age, 42 or 45% of students are 9 years old; 43 or 46% are 10 years old; and 8 or 9% are 11 years old.

To support the development of digital modules, it is also necessary to analyze students' technology accessibility. The results of this student technology accessibility analysis are presented in Table 6.

Table 6.
Students' Technology Accessibility

No.	Aspect	Yes	No
1.	Own a smartphone/tablet	89%	11%
2.	Have used an AR app	0%	100%
3.	Have internet access at home	97%	3%
4.	Familiar with mobile games	75%	25%

Table 6 above shows that 89% of students have a smartphone or tablet, 100% of students have never used an AR application, 97% of students have internet access at home, and 75% of students are familiar with mobile games.

Curriculum and Material Analysis

Based on the Learning Outcomes (Capaian Pembelajaran) for Mathematics in Phase B (Grades III-IV) and Phase C (Grades V-VI) as stipulated in Kepmendikbudristek No. 262/M/2022, the module development focuses on geometry.

The mapping of learning utcomes in geometry with module contexts is presented in Table 7.

Table 7.
Mapping of Learning Outcomes in Geometry with Module Contexts

Phase	Grade	Geometry Learning Outcomes	Focused Material in Module
Phase B	III	Students can describe the characteristics of various geometric shapes (quadrilaterals, triangles, polygons, and circles).	Recognition of geometric shapes through palace ornaments (tiles, windows, and doors).
	IV	Students can identify solid figures (prisms, cylinders,	Recognition of solid figures through

Phase	Grade	Geometry Learning Outcomes	Focused Material in Module
		cones, spheres) and calculate perimeter and area of squares and rectangles.	palace architecture; calculation of perimeter and area using floor tiles.
Phase C	V	Students can calculate the perimeter and area of various plane figures and calculate the volume of cubes and cuboids.	Calculation of perimeter and area using palace room contexts; volume calculation of main buildings.
	VI	Students can solve problems related to the surface area and volume of geometric shapes (prisms, cylinders); They can identify geometric nets.	Calculation of surface area and volume of palace buildings; identification of roof nets and building structures.

Source: Kepmendikbudristek No. 262/M/2022 concerning Changes to the 2013 Curriculum to the Independent Curriculum (processed)

Table 7a.
Mapping of Cultural Artifacts to Capaian Pembelajaran (CP) Kurikulum Merdeka

Buildings	Geometry Concepts	Geometry Learning Outcomes
Lawang Sanga (Nine Gates)	Rectangle, line symmetry, rotational symmetr	Phase B (Grades III-IV) Students can describe the characteristics of various two-dimensional shapes (triangle, quadrilateral, polygon) and can compose and decompose various 2D shapes using more than two shapes
Langgar Alit (Small Prayer Room)	Square pyramid, cube, rectangular prism, nets	Phase C (Grades V-VI) Students can recognize three-dimensional shapes (cube, rectangular prism, prism, pyramid, cylinder, cone, and sphere) and explain their characteristics based on the number of faces, edges, and vertices; Students can identify nets of simple 3D shapes.
Mande Pandawa Lima (Pavilion)	Triangular prism, perimeter, area, volume	Phase C (Grades V-VI) Students can calculate the surface area and volume of three-dimensional shapes (cube, rectangular prism, prism, and pyramid) and use them to solve problems.
Joglo Roof (Various Buildings)	Square pyramid, trapezoid, triangle	Phase B-C (Grades IV-VI) Students can explain and determine the perimeter and area of two-dimensional

Buildings	Geometry Concepts	Geometry Learning Outcomes
		shapes (triangle, quadrilateral, and their composites) using various strategies.
Door & Window Ornaments	Square, circle, line symmetry, repeating patterns	Phase B (Grades III-IV) Students can identify line symmetry and rotational symmetry in two-dimensional shapes and can create geometric patterns and explain the patterns formed.

Table 7b.
Derivation of Tujuan Pembelajaran (TP) from Capaian Pembelajaran for Module Development

Phase	Learning Objectives (LO)	Context of Kasepuhan Palace
Phase B (Grades III-IV)	LO 1: Identify and name 2D shapes (square, rectangle, triangle, trapezoid) on objects in the surrounding environment	Identifying geometric shapes on the doors, windows, and ornaments of Lawang Sanga
	LO 2: Determine line symmetry and rotational symmetry in 2D shapes	Analyzing line symmetry in the patterns of door and window ornaments of the Palace
	LO 3: Calculate the perimeter and area of squares and rectangles	Calculating the perimeter and area of floor tiles in the context of Palace rooms
Phase C (Grades V-VI)	LO 4: Identify the characteristics of 3D shapes (cube, rectangular prism, prism, pyramid) based on faces, edges, and vertices	Analyzing the structure of the Langgar Alit building and identifying the 3D shapes that compose it
	LO 5: Draw and identify nets of cubes, rectangular prisms, prisms, and pyramids	Creating nets of a Joglo roof (pyramid) and the Mande building (prism) using AR
	LO 6: Calculate the volume of cubes, rectangular prisms, prisms, and pyramids	Calculating the volume of the roof structure and the main body of the Mande Pandawa Lima building
	LO 7: Calculate the surface area of simple 3D shapes	Calculating the surface area of a roof for the context of painting or renovating historical buildings

The mapping of geometry learning outcomes and the module context above can be used as a reference to describe indicators and the cultural context in the Kasepuhan Palace that can be used as geometry learning materials. The geometry learning outcome indicators are presented in Table 8.

Table 8.
Geometry Learning Outcome Indicators

Phase	Learning Outcome	Indicator	Palace Context
B	Describe the	Identify the names and	All palace buildings

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Phase	Learning Outcome	Indicator	Palace Context
	characteristics of various plane and geometric shapes	characteristics of plane shapes (squares, triangles, circles) and geometric shapes (cubes, cuboids, prisms)	
B	Recognize the perimeter and area of squares and rectangles	Calculate the perimeter and area of squares and rectangles in real-world contexts.	Floors, tiles, doors, windows.
C	Calculate the perimeter and area of various plane shapes.	Calculate the perimeter and area of triangles, trapezoids, and compound shapes.	Roofs, ornaments, and gardens.
C	Calculate the volume and surface area of geometric shapes.	Calculate the volume and surface area of cubes, cuboids, prisms, and pyramids.	Building bodies, roofs, and pillars.
C	Identify nets of geometric shapes.	Draw and identify nets of cubes, cuboids, prisms, and pyramids.	All buildings

Cultural Context Analysis (Mathematical Exploration)

Through direct observation, an ethnomathematics exploration was conducted at the Kasepuhan Palace Cirebon on September 4, 2024. Throughout the observation process, researchers identified and analyzed architectural components and ornamental details that reflected geometric concepts. Direct observation, measurements, image recording, and interviews with Bapak Satu, a servant at the Kasepuhan Palace Cirebon, were conducted to gather the necessary information.

The analysis identified 84 solid figures across 13 palace buildings, as detailed in Table 9 and Table 10.

Table 9.
Recapitulation of Solid figure in the Buildings of Keraton Kasepuhan Cirebon

No	Solid Figure	Total	Found in Buildings
1	Cube	28	Langgar Alit, Mande Karesman, Mande Malang Semirang, Mande Pandawa Lima, Mande Semar Tinandu, Mosque, Museum, Buk Bacem Gate, Gledegan Gate, Regol Gate, Dewandaru Garden
2	Cuboid	27	All 13 buildings contain cuboid elements (foundation, walls, structure)
3	Triangular Prism	17	Langgar Alit, Mande Karesman, Mande Malang Semirang, Mande Pandawa Lima, Mande Pengiring, Mande Semar Tinandu, Mosque, Museum, Pendopo Pengada, Gledegan Gate, Regol Gate, Dewandaru Garden
4	Square Pyramid	5	Langgar Alit, Mande Pandawa Lima, Mande Pengiring, Museum, Dewandaru Garden
5	Sphere /	4	Museum, Buk Bacem Gate, Dewandaru

No	Solid Figure	Total	Found in Buildings
	Hemisphere		Garden
6	Cylinder	2	Dewandaru Garden (lamp posts)
7	Octagonal Prism	1	Dewandaru Garden (fountain area)
Total Overall		84	Solid figure across 13 buildings

Based on Table 9, it can be seen that of the 13 buildings in the Kasepuhan Palace, a total of 84 solid shape was identified. These spatial structures consist of 28 cubes, 27 cuboids, 17 triangular prisms, 5 rectangular pyramids, 4 spheres or half-spheres, 2 cylinders, and 1 octagonal prism.

Table 10.
Plane Figure Forming Solid Figure in the Buildings of Keraton Kesepuhan

Solid Figure	Plane Figure Component	Examples in Buildings	Related Concept
Cube	6 squares	Supporting pillars of Mande; Main Hall of the Mosque	Side, edges, vertex, diagonal
Cuboid	6 rectangles (3 pairs of congruent)	Building body, foundation, gate structure	Length, width, height, volume, surface area
Triangular Prism	2 triangles + 3 rectangles	Roof structures	Base, height of prism, nets, volume
Square Pyramid	1 square + 4 triangles	Joglo roof of Langgar Alit, Mande Pandawa	Base, height of pyramid, apothem, volume
Sphere / Hemisphere	Circles (cross-section)	Museum dome, ornament on Buk Bacem Gate	Radius, diameter, volume, surface area
Cylinder	2 circles + 1 rectangles	Lamp posts in Dewandaru Garden	Radius, height, lateral surface, volume
Octagonal Prism	2 octagons + 8 rectangles	Fountain area in Dewandaru Garden	Regular n-gons, rotational symmetry

Table 10 shows that there are several plane figures scattered throughout the Kasepuhan Palace buildings, such as squares, rectangles, triangles, circles, and octagons. Related concepts that can be learned include those, regarding edges, vertex, sides, diagonals, length, width, height, volume, bases, nets, diameters, apothems, and rotational symmetry.

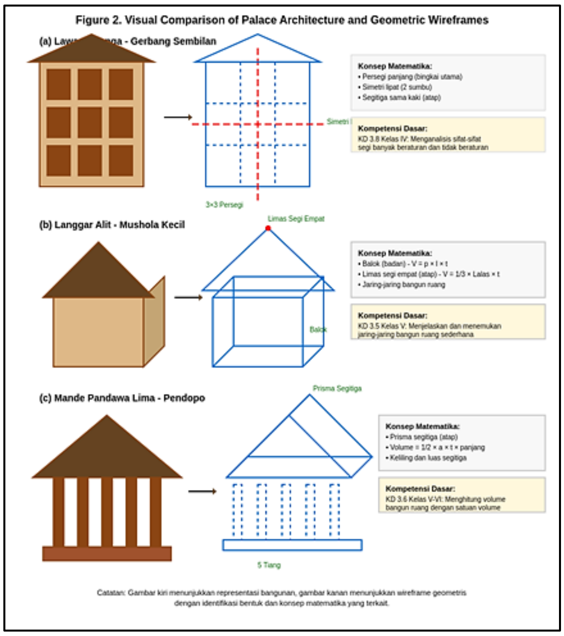

Figure 2. shows the geometric analysis of three main buildings: (a) Lawang Sanga with rectangular symmetry, (b) Langgar Alit with pyramidal roof structure, and (c) Mande Pandawa Lima with triangular prism roof.

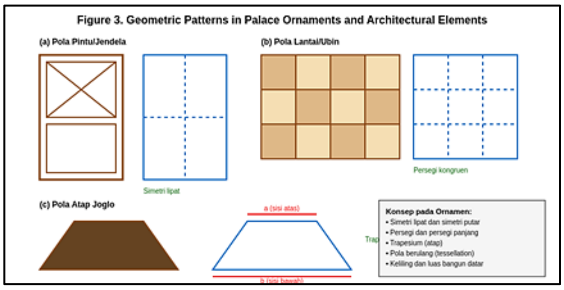

Figure 3. illustrates the geometric patterns found in palace ornaments: (a) door/window frames with symmetry, (b) floor tile patterns showing congruent squares, and (c) joglo roof trapezoid shapes.

B. Discussion

Integration of Multidimensional Analysis Findings

The multidimensional analysis framework employed in this study reveals interconnected findings that collectively validate the urgency of developing AR-based digital ethnomathematics modules

Dimension 1: Needs Analysis (Technology Acceptance Model Perspective)

From the needs analysis perspective, grounded in the Technology Acceptance Model (TAM), the findings indicate high perceived usefulness (100% teacher agreement on AR's potential to enhance engagement) and favorable conditions for perceived ease of use (89% device ownership, 97% internet access). Teachers explicitly expressed that current textbook-based geometry instruction fails to adequately support students' spatial reasoning development. The disconnect between abstract geometric concepts and students' concrete experiences creates a pedagogical gap that AR technology can address by providing interactive, manipulable 3D representations. These findings align with Davis's (1989) assertion that perceived usefulness and ease of use are primary determinants of technology acceptance in educational contexts.

Dimension 2: Student Characteristics (Piaget's Cognitive Development Theory)

The learner characteristics analysis, informed by Piaget's cognitive development theory, confirms that target students (ages 9-11) are in the concrete operational stage, during which they benefit from manipulating real objects and viewing visual representations. This finding is consistent with (Ilhami, 2022) interpretation that children at this developmental stage learn more effectively through hands-on experiences and concrete visualizations. The alignment between AR technology and Piagetian developmental principles is particularly noteworthy. During the concrete operational stage, children can perform mental operations on concrete objects but struggle with purely abstract reasoning. AR technology bridges this developmental gap by transforming abstract geometric concepts into manipulable virtual objects overlaid on familiar cultural artifacts. Students can virtually rotate 3D shapes, unfold geometric nets, and measure angles—operations that would be impossible with traditional 2D textbook representations or physical models of protected heritage buildings. The fact that 100% of students have never used AR applications for learning represents both a gap and an opportunity—introducing AR as a novel learning experience could leverage students' existing familiarity with mobile games (75%) while providing developmentally appropriate visual learning supports.

Dimension 3: Curriculum Alignment

The curriculum analysis establishes clear alignment between the proposed module content and official Learning Outcomes in Phases B and C. The geometry concepts identified in Keraton Kasepuhan—including plane figures, solid figures, perimeter, area, volume, and geometric nets—correspond directly to curricular requirements across grades III through VI. The explicit mapping presented in Table 7a demonstrates that Keraton Kasepuhan's architectural elements can serve as authentic contexts for achieving specific Kompetensi Dasar (KD) mandated in the Kurikulum Merdeka. For instance, the Lawang Sanga gateway structure directly supports KD 3.8 (analyzing properties of regular and irregular polygons), while the Langgar Alit's pyramidal roof structure supports KD 3.5 (explaining and discovering nets of simple solid figures). This curriculum-heritage alignment ensures that the proposed module serves educational mandates while enriching learning through cultural contextualization rather than treating cultural content as supplementary material. This alignment ensures that the proposed module serves educational mandates while enriching learning through cultural contextualization.

Dimension 4: Cultural Context and Philosophical Values

The cultural context analysis, grounded in D'Ambrosio's (2001) ethnomathematics perspective, demonstrates the rich mathematical heritage embedded within Keraton Kasepuhan's architecture. The identification of 84 solid figures and diverse plane figures across 13 buildings provides substantial content for authentic ethnomathematics integration.

Beyond geometric identification, the cultural context analysis reveals profound philosophical values embedded in the architectural mathematics. Lawang Sanga (Nine Gates), for example, embodies the Javanese-Islamic concept of "Sanga" representing the nine wali (Islamic saints) who spread Islam in Java. The symmetrical design reflects the principle of balance (keseimbangan) central to Cirebonese cosmology, while the precise geometric proportions demonstrate the mathematical sophistication of traditional Sundanese-Javanese architects. Similarly, the Mande Pandawa Lima pavilion, named after the five Pandawa brothers from the Mahabharata epic, uses pentagonal symmetry elements that symbolize the five pillars of Islam and the five senses. These philosophical underpinnings transform

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geometry lessons from mere shape identification into meaningful cultural experiences that connect mathematical concepts with students' cultural identity and heritage pride. The integration of these values into AR-based learning creates opportunities for holistic education that addresses both cognitive and affective learning domains.

This finding corroborates Fathimah et al.'s (2025) research on the geometric elements present in Kasepuhan Palace architecture, while extending the analysis to include specific pedagogical applications.

Theoretical and Practical Implications

The theoretical implications of this study contribute to the conceptual understanding of technology-culture integration in mathematics education. The multidimensional analysis framework developed and applied in this study offers a systematic approach that can be adapted for similar ethnomathematics-based media development in other cultural contexts. By synthesizing TAM, cognitive development theory, and ethnomathematics perspectives, this framework addresses a gap in the literature regarding comprehensive pre-development analysis methodologies.

The practical implications are equally significant. The findings provide empirical justification for educational technology investment, demonstrating that stakeholders (teachers and students) perceive value in AR-based ethnomathematics approaches. The detailed mapping of geometric concepts to specific palace architectural elements (Tables 7 and 8) offers a practical blueprint for module content development. Furthermore, the identification of technology accessibility patterns informs decisions about technical requirements and deployment strategies.

Comparison with Previous Research

This study's findings are consistent with previous research demonstrating the effectiveness of AR-based ethnomathematics learning media. Hayati and Salsabila (2023) found that AR with ethnomathematics approaches enhances understanding of solid figures. Similarly, Khasanah et al. (2024) reported that interactive AR media integrated with ethnomathematics improves learning engagement in elementary schools. Umri et al. (2025) demonstrated the feasibility of developing AR-based ethnomathematics media using cultural heritage sites (Candi Prambanan). This study extends this body of research by providing a comprehensive pre-development analysis that strengthens the theoretical and empirical foundation for such developments.

A distinctive contribution of this study is its systematic attention to the analysis phase, which previous research has often treated superficially. Suntari et al. (2025) similarly observed that many teachers still use conventional methods and lack engaging visualizations, reinforcing the need identified in this study. By providing detailed analysis across four interconnected dimensions, this study offers a more robust foundation for subsequent development and implementation phases.

Limitations

This study has several limitations that should be acknowledged. First, the analysis was conducted within a specific cultural and geographic context (Cirebon Regency and Keraton Kasepuhan), which may limit generalizability. Second, this study focuses exclusively on the analysis stage of ADDIE; subsequent research should report on design, development, implementation, and evaluation phases to provide complete evidence of module effectiveness. Third, the sample size for needs analysis (n=23) was relatively small; larger-scale surveys could strengthen the empirical foundation. Fourth, the study did not include comparative analysis with other palace complexes in Indonesia, which could have provided broader validation of the analytical framework. Fifth, the cultural context analysis was limited to a single visit, which may not capture seasonal or temporal variations in palace activities and accessibility.

IV. Conclusion

This study presents a multidimensional analysis for developing an augmented reality-based digital ethnomathematics module utilizing the cultural heritage of Keraton Kasepuhan Cirebon for elementary school geometry education. Through the integration of the Technology Acceptance Model, Piaget's cognitive development theory, and D'Ambrosio's ethnomathematics framework, the analysis demonstrates compelling evidence for the urgency and feasibility of module development.

Key findings include: (1) all teachers (100%) agreed that AR-based media could enhance student engagement in geometry learning; (2) 90% of students expressed enthusiasm for culturally-based mathematics learning; (3) target students (ages 9-11) are developmentally suited for AR-enhanced visual learning; (4) 84 solid figures and numerous plane figures were identified across 13 palace buildings, providing rich content for module development; and (5) clear alignment exists between identified geometric elements and curriculum requirements in Phases B and C.

The novelty of this research lies in the development and application of an integrated multidimensional analysis framework that systematically examines needs, learner characteristics, curriculum, and cultural context as interconnected dimensions. This framework provides a replicable methodological approach for future ethnomathematics-based learning media development.

The findings from this multidimensional analysis serve as a comprehensive blueprint (cetak biru) for the subsequent Design and Development stages of the ADDIE model. Specifically, the needs analysis data inform the instructional objectives and content scope; the learner characteristics data guide interface design and interaction complexity; the curriculum mapping ensures alignment with mandatory learning outcomes; and the cultural context analysis provides authentic content for ethnomathematics integration. This blueprint ensures that the module development will be grounded in empirical evidence rather than assumptions.

Contributions to Mathematics Education: This study makes three primary contributions to the field of mathematics education. First, it introduces an integrated multidimensional analysis framework that synthesizes TAM, Piagetian theory, and ethnomathematics—a theoretical integration not previously articulated in the literature. Second, it provides a documented methodology for systematically analyzing cultural heritage sites for mathematics education potential, which can serve as a template for researchers in other contexts. Third, it offers empirical evidence supporting the pedagogical value of combining AR technology with ethnomathematics approaches, addressing the need for pre-development validation in educational technology research.

Implications: The implications of this study extend to multiple stakeholders. For curriculum developers, the findings suggest that local cultural heritage can and should be systematically integrated into mathematics curricula to enhance relevance and engagement. For educational technology developers, the study demonstrates the importance of comprehensive pre-development analysis in creating contextually appropriate learning tools. For cultural heritage managers, the findings highlight the educational potential of heritage sites and the non-invasive nature of AR-based educational interventions. For policymakers, the study provides evidence supporting investment in culturally-responsive educational technology initiatives.

Recommendations: Based on the findings and limitations of this study, the following recommendations are offered: (1) Researchers are encouraged to apply the "Multidimensional Analysis" framework developed in this study to other cultural heritage sites across Indonesia and beyond, such as Candi Borobudur, Kraton Yogyakarta, Rumah Gadang, and other culturally significant architectural sites, to validate and refine the framework's applicability; (2) Future studies should complete the full ADDIE cycle to empirically evaluate the developed module's effectiveness in improving learning outcomes; (3) Collaborative research involving mathematics educators, cultural anthropologists, and AR developers is recommended to ensure both pedagogical soundness and cultural authenticity; (4) Longitudinal studies examining the sustained impact of AR-based ethnomathematics learning on both mathematical achievement and cultural awareness are warranted.

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AUTHOR'S BIOGRAPHY

Dian Anggraeni Maharbid, M.Pd.

Born in Cirebon on July 26, 1989. She is a lecturer in the Elementary School Teacher Education Study Program at Bhayangkara Jakarta Raya University. She earned her Bachelor's degree in Elementary School Teacher Education from Universitas Pendidikan Indonesia (UPI), Bandung, in 2011, and completed her Master's degree in Elementary Education at the same university in 2016. She is currently pursuing her doctoral studies at Universitas Pendidikan Indonesia.

Prof. Dr. Tatang Herman, M.Pd.

Born in Garut October 11, 1962. Professor at the Indonesian University of Education. Study S-1 Mathematics Education, IKIP Bandung, graduated in 1989; S-2 Mathematics Education, Deakin University Melbourne Australia, graduated in 1996; and S-3 Mathematics Education, Indonesian University of Education, graduated in 2006.

Prof. Dr. Mubiar Agustin, M.Pd.

Professor at the Indonesian University of Education. Study S-1 Psychology Education and Counseling Guidance, IKIP Bandung; S-2 and S-3 Guidance and Counseling, Indonesian University of Education.

Dr. Cepi Riyana, M.Pd.

Lecturer at the Indonesian University of Education. Study S-1 educational technology, IKIP Bandung; S-2 and S-3 curriculum development, Indonesian University of Education.

Ejen Jenal Mutaqin, M.Pd.

Born in Garut, July 16, 1986. Lecturer at the Elementary School Teacher Education Study Program, Indonesian Education Institute Garut. The author's education comes from the S1 Elementary School Teacher Education level at the Indonesian Education University Bandung, graduated in 2010, and the S2 Elementary Education level at UPI, graduated in 2013, and is currently continuing his doctoral studies at the Indonesian Education University.