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Geometric Sequences In The Tiered Architecture of Candi Singosari and Candi Sumberawan: An Ethnomodelling Exploration For Teaching Sequences and Series

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ABSTRACT

Ethnomathematical studies of Indonesian temples have overwhelmingly examined plane and solid geometry, leaving other mathematical structures embedded in heritage architecture largely unexplored. This study explores how the concept of sequences, specifically the distinction between arithmetic (additive) and geometric (multiplicative) sequences, is embodied in two monuments on the slopes of Mount Arjuno, East Java: the Śaiva-Buddhist Candi Singosari and the Buddhist stupa of Candi Sumberawan. Using an ethnographic-exploratory design framed by ethnomodelling, the study combined documentary analysis of historical and conservation sources with image-based mensuration of the receding roof tiers, the square terraces, and the stacked rings of the stupa. Successive differences and ratios were computed, and arithmetic and geometric models were fitted and compared. The roof tiers of Singosari ($r \approx 0.838$) and the terraces of Sumberawan ($r \approx 0.820$) were better described by geometric sequences: their ratios varied by less than 4%, whereas their differences varied by 26–32%, and both ratios lay close to a one-sixth reduction per level (5/6). The stupa rings showed a gentle taper ($r \approx 0.91$) for which both models were almost equivalent, illustrating that a geometric sequence with a ratio near 1 behaves locally like an arithmetic one. The Meru logic of the candi, in which each level is a scaled replica of the one below rising towards a finite summit, can therefore be read as a geometric sequence and its convergent series. The study contributes a non-geometric, data-driven ethnomathematical context and a learning design for teaching sequences and series.

Keywords: Ethnomathematics; Arithmetic and Geometric Sequences; Candi Singosari; Candi Sumberawan; Ethnomodelling

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INTRODUCTION

Ethnomathematics studies the ways in which cultural groups count, measure, locate, design, play, and explain, and treats these practices as legitimate forms of mathematical knowledge (D'Ambrosio, 1985; Bishop, 1988). Beyond documenting "mathematics in culture", the field asks how such knowledge can be made visible, interpreted, and brought into dialogue with school mathematics without stripping it of its cultural meaning (Barton, 1996; Rosa & Orey, 2011). Ethnomodelling extends this programme by treating cultural artefacts as systems that can be described by mathematical models built from emic (insider), etic (outsider), and

dialogic perspectives (Rosa & Orey, 2016). In this view, an artefact is not merely a source of shapes to be named, but a source of data whose regularities can be measured, modelled, and tested.

Indonesia has become one of the most productive sites of ethnomathematical research. Studies have shown how Yogyakarta batik encodes geometric transformations and values (Prahmana & D'Ambrosio, 2020), how the Javanese *pranatamangsa* calendar and birth–death ceremonies rely on modular arithmetic and mathematical modelling (Prahmana et al., 2021), how shadow puppetry can support the learning of set theory (Prahmana & Istiandaru, 2021), and how a Buginese cake offers contexts for mathematics learning (Pathuddin et al., 2021). Javanese culture more broadly has been mapped as a reservoir of counting, measuring, and designing activities (Risdiyanti & Prahmana, 2017). Temples (*candi*) occupy a special place in this literature because they are monumental, publicly accessible, and widely used as field-trip destinations; Sewu (Sulistyowati & Khotimah, 2022), Ngawen (Sariningtias et al., 2020), and the artefacts of the Singhasari kingdom (Wulandari & Budiarto, 2020) have all been explored.

The state of the art, however, reveals a strong convergence. Systematic reviews report that geometry dominates ethnomathematical research, with ethnography as the default method and the identification of shapes as the default outcome (Iskandar et al., 2022; Kyeremeh et al., 2023). A review dedicated to temple ethnomathematics concluded that mathematical findings across studies are largely the same, with little novelty from one site to another, and that the connection between the mathematical and the cultural remains weak (Fuat et al., 2024). Where non-geometric ideas appear, they are usually by-products: Sewu and the Singhasari artefacts are reported to contain "number patterns" or "arithmetic sequences", but these are identified by counting repeated elements rather than by measuring and testing the regularity itself (Sulistyowati & Khotimah, 2022; Wulandari & Budiarto, 2020). The research gap is therefore twofold. Substantively, the sequence structure of tiered temple architecture, which is arguably its most defining feature, has not been examined as a mathematical object in its own right. Methodologically, previous studies have not asked which type of sequence best describes a cultural pattern, although distinguishing additive from multiplicative growth is precisely where students struggle when generalising patterns (Rivera & Becker, 2008; Radford, 2010).

Candi Singosari and Candi Sumberawan, both located in Malang Regency on the slopes of Mount Arjuno, provide an unusually clear opportunity to address this gap. Candi Singosari is a thirteenth-century Śaiva-Buddhist sanctuary associated with the commemoration of King Kertanegara (r. 1268–1292), the last ruler of Singhasari, and is mentioned in the *Deśawarṇana* (*Nāgarakṛtāgama*) (Robson, 1995). Its body is crowned by a stack of receding roof tiers. Candi Sumberawan is the only stupa-form Buddhist monument in East Java; it consists of a square base, a pedestal, and a bell-shaped stupa formed by stacked rings, and it is commonly identified with the Kasurangganan visited by King Hayam Wuruk in 1359 (Balai Pelestarian Cagar Budaya Jawa Timur, 2015; Robson, 1995). In Javanese temple architecture, such vertical stacking expresses the cosmic mountain Meru, with each level read as a step nearer to the sacred summit (Degroot, 2009). Because both monuments are built as a sequence of levels that become smaller with height, they invite a precise mathematical question: does each level shrink by a constant amount or by a constant proportion?

Accordingly, the objectives of this study were (1) to identify and quantify the sequence structures embodied in the roof tiers of Candi Singosari and in the terraces and rings of Candi Sumberawan; (2) to determine whether these structures are better described by arithmetic or geometric sequences; and (3) to translate the findings into a culturally grounded learning design for sequences and series. The argument advanced is that the Meru principle of "a smaller

replica upon a larger one" is, mathematically, a multiplicative rule, so that the stepped levels of the candi should follow a geometric rather than an arithmetic sequence, and that the finite summit towards which they rise can be interpreted through the sum of a convergent geometric series.

METHOD

This section describes the research design, the objects and data sources, the data collection procedures, and the analysis used to model the sequence structures of the two monuments.

Research Design

The study employed a qualitative ethnographic-exploratory design framed by ethnomodelling (Rosa & Orey, 2016), complemented by quantitative mensuration. The emic perspective was represented by the cultural and historical meanings of the monuments as recorded in primary and conservation sources; the etic perspective was represented by the measurement and modelling of their tiered forms; and the dialogic perspective brought the two together to interpret the models culturally and to design learning activities. A single mathematical topic, sequences and series, was deliberately chosen to avoid the plane- and solid-geometry focus that dominates the literature (Fuat et al., 2024; Iskandar et al., 2022).

Research Objects and Data Sources

The research objects were purposively selected for three architectural units in which levels diminish systematically with height: (a) the receding roof tiers of Candi Singosari above the main body cornice; (b) the three square levels of Candi Sumberawan, namely the base, the pedestal, and the stupa pedestal; and (c) the stacked circular rings forming the body of the Sumberawan stupa. Data were drawn from four photographs, two of each monument (Figures 1 and 2 show the two sites; the frontal view of Singosari and an oblique view of Sumberawan were used for measurement); the official dimensions of Candi Sumberawan published by the East Java Cultural Heritage Preservation Office, namely a base of 6.30 m, a pedestal of 5.04 m, and a stupa pedestal of 4.24 m per side (Balai Pelestarian Cagar Budaya Jawa Timur, 2015); and historical sources on the function and meaning of the two monuments (Degroot, 2009; Robson, 1995).

Data Collection

Data were collected through documentation and digital mensuration. Each photograph was analysed at its native resolution and overlaid with a calibrated pixel grid (5 px and 10 px intervals). For every level, the outermost horizontal extent of the cornice (Singosari and the Sumberawan terraces) or of the ring bulge (Sumberawan rings) was read in pixels and repeated to estimate a reading error of about ±2–3 px. Because the analysis concerns ratios between successive levels, all values were normalised by the first term, which removes the unknown image scale. Two properties of the views support this procedure. First, the apparent width of a circular ring does not depend on the viewing direction, so the oblique Sumberawan view is adequate for the rings. Second, the frontal Singosari view was taken perpendicular to the façade, so the roof tiers lie in nearly parallel planes; the residual perspective error, which slightly shrinks higher tiers, is discussed as a limitation. The Sumberawan terrace values were taken directly from the published dimensions, which serves as an independent, metric check on the image-based results.

Data Analysis Techniques

The analysis followed three steps. First, the emic data were analysed descriptively to characterise each unit and its cultural role. Second, for each measured sequence $x_1, x_2, \ldots, x_k$ (ordered from bottom to top), the successive differences $\Delta_n = x_{n+1} - x_n$ and ratios $\rho_n = x_{n+1}/x_n$ were computed, and their coefficients of variation (CV) were compared: an approximately constant difference indicates an arithmetic sequence, whereas an approximately constant ratio indicates a geometric one. The two rival models were then fitted by ordinary least squares, the geometric model in its log-linear form:

$$u_n = a + (n - 1)d \tag{1}$$

$$u_n = a \cdot r^{n-1} \iff \ln u_n = \ln a + (n - 1) \ln r \tag{2}$$

Model fit was compared through the coefficient of determination (R^2) and the root-mean-square error normalised by the first term (nRMSE). Third, in the dialogic step, the fitted models were used to compute partial and infinite sums, which were interpreted against the cultural meaning of the monuments and translated into learning tasks:

$$S_n = (n/2)[2a + (n - 1)d], \quad S_n = a(1 - r^n)/(1 - r), \quad S_\infty = a/(1 - r) \text{ for } |r| < 1 \tag{3}$$

RESULTS AND DISCUSSION

Results

Emic description of the tiered forms. Candi Singosari rises from a high base to a square body containing the cella, whose entrances are surmounted by *kāla* heads. Above the body cornice the roof is built as a stack of receding tiers, each repeating the profile of the one beneath it on a smaller scale and ending in a crowning block. Candi Sumberawan, by contrast, has no cella; its square base, pedestal, and stupa pedestal form three receding platforms, upon which a bell-shaped stupa is built from stacked rings whose diameters decrease towards the top (Figures 1 and 2). In both monuments the vertical order carries meaning: ascending the levels corresponds to approaching the summit of Meru, the axis of the cosmos (Degroot, 2009). The architectural vocabulary is therefore one of *repetition with reduction*, which is exactly what a sequence formalises.



Figure 1. Candi Singosari, Malang Regency, East Java



Figure 2. Candi Sumberawan, Toyomarto, Malang Regency, East Java

Etic quantification: differences versus ratios. Figure 3 shows how the roof tiers of Singosari were read as the terms u_1, u_2, u_3 of a sequence, and Figure 4 shows the terraces w_1, w_2, w_3 and the rings v_1, …, v_5 of Sumberawan. Table 1 summarises the measured values and the tests of constancy. For the three Singosari roof tiers, the widths fell from 173 to 142.5 and then to 121.5 px. The differences (−30.5, −21.0 px) changed considerably (CV = 26.1%), whereas the ratios (0.824, 0.853) were almost constant (CV = 2.4%). The published Sumberawan terraces showed the same behaviour: the differences (−1.26 m, −0.80 m; CV = 31.6%) were unstable, while the ratios (0.800, 0.841; CV = 3.6%) were nearly constant. In both cases the geometric model fitted better than the arithmetic model (Table 1). The body cornice of Singosari (u_0 = 284 px) is markedly wider than the first roof tier (ratio 0.61); it belongs to the body rather than to the roof and therefore marks the starting point of the roof sequence rather than one of its terms.



Figure 3. Roof Tiers of Candi Singosari Read as a Geometric Sequence (widths u_n and vertical rises h_n)



Figure 4. Terraces (w_n) and Stupa Rings (v_n) of Candi Sumberawan Read as Sequences

Table 1. Measured widths and tests of arithmetic versus geometric sequence models

Sequence (bottom → top)	Measured values	Differences / ratios (CV)	Model fit (R^2; nRMSE)
Singosari roof tiers u_1–u_3	173; 142.5; 121.5 px	Δ: −30.5, −21.0 (26.1%) ρ: 0.824, 0.853 (2.4%)	Arithmetic: 0.989; 1.29% Geometric: 0.997; 0.68% r = 0.838
Sumberawan terraces w_1–w_3	6.30; 5.04; 4.24 m (published)	Δ: −1.26, −0.80 (31.6%) ρ: 0.800, 0.841 (3.6%)	Arithmetic: 0.984; 1.72% Geometric: 0.995; 0.97% r = 0.820
Sumberawan rings v_1–v_5	180; 162; 151.6; 137; 122 px	Δ: −18.0, −10.4, −14.6, −15.0 (21.6%) ρ: 0.900, 0.936, 0.904, 0.891 (2.2%)	Arithmetic: 0.995; 0.79% Geometric: 0.993; 0.92% d = −14.1 px; r = 0.910

Figure 5 plots the normalised widths of the three sequences against the level index together with the fitted arithmetic and geometric models. The Singosari tiers and the Sumberawan terraces lie almost on the same geometric curve, with common ratios of 0.838 and 0.820, respectively. Both are within 2% of the reference ratio 5/6 ≈ 0.833 (deviations of +0.6% and −1.6%), so each level is, to a close approximation, five-sixths of the level beneath it. The stupa rings follow a much gentler taper. For them, the ratios were the more stable quantity (CV = 2.2% versus 21.6% for the differences), whereas R^2 and nRMSE slightly favoured the arithmetic model; the two fitted curves are almost indistinguishable in Figure 5.

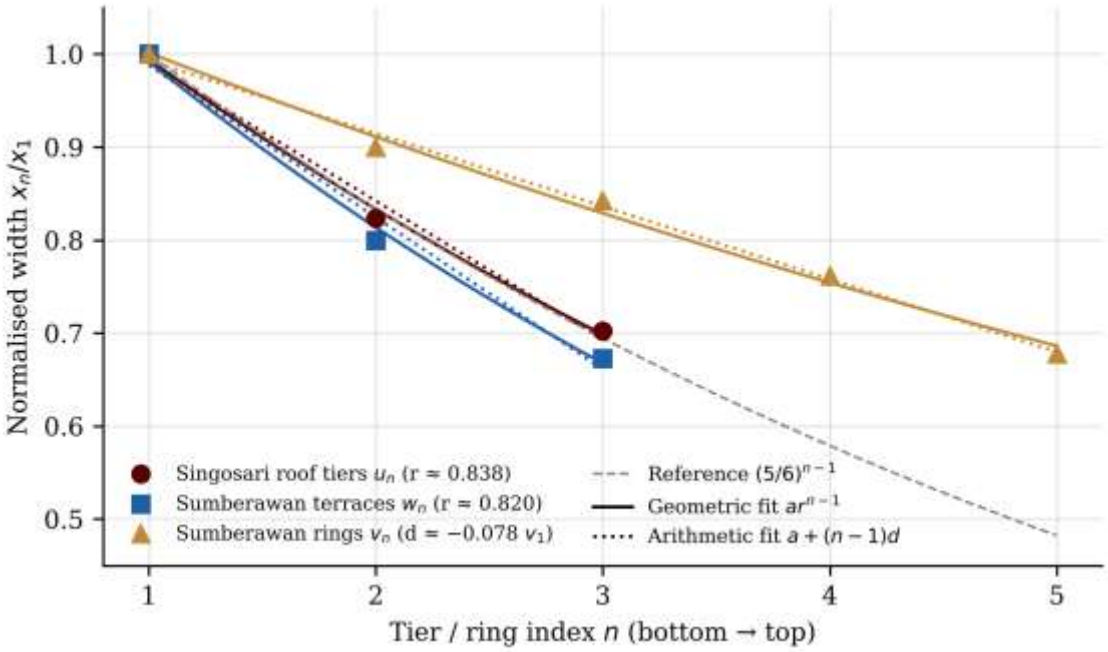

Figure 5. Arithmetic and Geometric Models Fitted to the Normalised widths of the Tiers, Terraces, and Rings

This near-equivalence has a simple mathematical explanation. For a ratio close to 1, write $r = 1 + \varepsilon$ with ε small; then $a \cdot r^{n-1} \approx a[1 + (n-1)\varepsilon]$, which is an arithmetic sequence with $d \approx a\varepsilon$. With a = 180 px and r = 0.910 ($\varepsilon = -0.090$), the approximation predicts $d \approx -16.2$ px, close to the fitted d = −14.1 px. The rings therefore do not contradict the multiplicative reading; they show the regime in which a multiplicative rule with a gentle ratio produces an almost linear profile, and hence the smooth bell of the stupa. The stepped terraces and tiers, whose ratio is further from 1, display the multiplicative character clearly.

Extension to series. The models also support meaningful sums. For the Sumberawan terraces, the geometric model (a = 6.247 m, r = 0.820) gives $S_3 = a(1 - r^3)/(1 - r) = 15.58$ m, which matches the sum of the published widths (6.30 + 5.04 + 4.24 = 15.58 m); multiplied by four, this is the total edge length of the three square levels (62.32 m). For the stupa rings, scaling the image by the published stupa pedestal (4.24 m ≈ 208 px; about 0.020 m/px) gives estimated diameters of 3.67–2.49 m, an arithmetic sum of $S_5 \approx 15.34$ m, and a combined ring circumference of about 48.2 m. Finally, the vertical spacing of the Singosari roof also recedes: the rise from the body cornice to the first tier (30 px) and from the first to the second tier (25 px) has a ratio of 0.833. If this reduction continued indefinitely, the total rise would be bounded by $S_\infty = 30/(1 - 0.833) = 180$ px; the observed rise from the body cornice to the apex is about 150 px, within this bound. A convergent series thus gives a precise mathematical form to the Meru image of an ascent that continues level after level yet terminates in a finite summit.

Integration into learning. Table 2 translates the findings into a learning sequence in which students move from the cultural artefact to a mathematical model and back again, in line with ethnomodelling.

Table 2. Learning design for sequences and series based on Candi Singosari and Candi Sumberawan

Phase	Cultural context	Sequence concept	Student task
Emic	Meaning of Meru, roof tiers and stupa rings	Sequence as an ordered list of terms	Describe how each level relates to the one below it
Etic	Measured tier, terrace and ring widths	Differences versus ratios; arithmetic and geometric sequences	Compute Δ and ρ and decide which one is constant
Modelling	Normalised widths (Figure 5)	General terms $u_n = a + (n-1)d$ and $u_n = ar^{n-1}$	Fit both models and compare predictions
Series	Terrace edges, ring circumference, roof height	Finite sums S_n; infinite sum S_∞	Compute total lengths; interpret the finite summit
Dialogic	Restoration and builders' proportions	Model limits; $r \approx 1$ approximation	Discuss what the models can and cannot claim

Discussion

The findings extend previous temple ethnomathematics in two respects. First, earlier studies of Sewu and of the Singhasari artefacts mentioned arithmetic sequences or number patterns, but derived them from counts of repeated elements (Sulistyowati & Khotimah, 2022; Wulandari & Budiarto, 2020). The present study measured the regularity and tested competing models, and found that the dominant structure of the tiered levels is multiplicative rather than additive. This shifts the analysis from naming what is visible to explaining how the form is generated, which responds directly to the criticism that temple studies have converged on similar and weakly contextualised findings (Fuat et al., 2024). Second, the study treats a cultural artefact as a dataset for model comparison, which operationalises the etic and dialogic dimensions of ethnomodelling (Rosa & Orey, 2016) and moves beyond the geometric focus reported in systematic reviews (Iskandar et al., 2022; Kyeremeh et al., 2023).

Culturally, the multiplicative reading fits the logic of Javanese temple design, in which the superstructure is composed of reduced repetitions of the body, so that the temple becomes a replica of Meru built of smaller replicas of itself (Degroot, 2009). A constant ratio is the mathematical expression of "the same form at a smaller scale", whereas a constant difference would not preserve proportion. The similarity of the ratios at the two sites (0.838 and 0.820, both near 5/6) is striking given their different religious affiliations, namely a Śaiva-Buddhist sanctuary and a Buddhist stupa, and possibly different periods. It suggests a shared proportional practice in the Arjuno region, perhaps based on modular units. This must remain a hypothesis: agreement within a few per cent over two or three terms can arise by chance, and the history of the "golden ratio" in architecture warns against reading exact constants into approximate data (Markowsky, 1992).

Pedagogically, the contrast between the stepped terraces and the gently tapering rings is the most valuable outcome. Students often apply additive reasoning by default when generalising patterns and find it difficult to recognise multiplicative structure or to justify their choice of rule (Radford, 2010; Rivera & Becker, 2008). The candi offers authentic data in which the choice between the two rules is neither obvious nor arbitrary, and the rings show that the two rules can coincide locally, which provides an intuitive entry into linear approximation. Integrating culturally meaningful contexts has been shown to strengthen mathematical thinking (Fouze & Amit, 2018) and to connect mathematics with students' heritage (Prahmana & D'Ambrosio, 2020; Prahmana et al., 2021). At the same time, teachers often lack the content and cultural knowledge needed to use such contexts (Sunzuma & Maharaj, 2019). The measured values in Table 1 and the design in Table 2 are intended to lower this barrier by giving teachers ready-to-use data and tasks.

Several limitations should be acknowledged. The sequences are short (three to five terms), which limits the power to discriminate between models. The image-based measurements carry reading errors of about ±2–3 px and, for Singosari, a small perspective reduction of the higher tiers that may lower the estimated ratio slightly. Candi Sumberawan was restored in 1937 with only partial original material in the upper parts, so the ring profile may partly reflect the reconstruction rather than the original design (Balai Pelestarian Cagar Budaya Jawa Timur, 2015). Future research should (1) verify the values with on-site laser or total-station measurement of all faces; (2) include interviews with site custodians (*juru kunci*), archaeologists, and local craftspeople to strengthen the emic perspective; (3) extend the analysis to other tiered candi such as Kidal, Jago, and Jawi to test the 5/6 hypothesis; and (4) implement and evaluate the learning design through design-based research in secondary classrooms.

CONCLUSION

This study explored the concept of sequences in the tiered architecture of Candi Singosari and Candi Sumberawan and showed that tiered temple architecture contains mathematical structure beyond plane and solid shapes. The receding roof tiers of Singosari and the square terraces of Sumberawan are best described by geometric sequences with common ratios of 0.838 and 0.820. Both ratios lie close to five-sixths, whereas the differences between successive levels are far from constant. The stacked rings of the Sumberawan stupa show a gentle taper in which arithmetic and geometric models nearly coincide. All three objectives were therefore achieved: the sequence structures were identified and quantified, the multiplicative nature of the stepped levels was established, and a learning design was derived from the findings.

Theoretically, the study shows that the Meru principle of a smaller replica placed upon a larger one can be formalised as a geometric sequence, and that the image of a finite summit reached through successive levels corresponds to the convergence of a geometric series. Methodologically, it shows how ethnomodelling can turn a heritage monument into a dataset for comparing models, which addresses the convergence and weak cultural connection identified in temple ethnomathematics. Practically, it gives teachers authentic data and tasks for teaching the distinction between additive and multiplicative growth, finite and infinite sums, and the limits of mathematical models.

Future studies should validate the measurements in the field, deepen the emic perspective through interviews with custodians and archaeologists, test the proportional hypothesis across other East Javanese candi, and evaluate the learning design empirically in classrooms.

DECLARATIONS

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Author Contributions Statement

Frista Andiani: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – Original Draft, and Writing – Review & Editing.

AI Usage Statement

During the preparation of this manuscript, the author used an AI-based tool to assist with drafting the text, image-based measurements, model fitting, and the preparation of Figures 3–5. The author reviewed, verified, and edited all outputs, checked every reference against its original source, and takes full responsibility for the accuracy and integrity of the content of this publication.

Conflict of Interest

The author declares that there are no conflicts of interest related to the research, authorship, and/or publication of this article.

Data Availability

The measurement data supporting the findings of this study (Table 1) are available from the corresponding author upon reasonable request.

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Ethical Approval

Not applicable. This study did not involve human participants or animals.

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