14th National Conference on
Role of Engineers in Nation Building NCRENB-2026 organized by VIVA Institute of Technology, Mumbai
on 6th & 7th MARCH 2026
International Journal of Engineering Research & Science (IJOER) ISSN: [2395-6992] [Vol-12, Issue-3, March 2026]

KolamGen: Mathematical Formulas for Traditional Kolam Pattern Generation

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Abstract— *KolamGen is a Flutter-based interactive application that enables users to generate and explore traditional South Indian Kolam patterns through mathematical visualization. The system applies algorithmic models such as Sikku modular paths, Hridaya Kamalam grid connections, Lissajous curves, spirograph hypocycloids, harmonic motion, and fractal recursion. It demonstrates Eulerian single-stroke construction, symmetry rules, and grid-based pattern logic. Users can interactively adjust parameters like grid size and skip values while observing animated, step-by-step drawing and real-time mathematical validation. By allowing hands-on pattern creation and immediate visual feedback, the application helps users understand the mathematical principles governing Kolam construction, bridging cultural art with computational geometry.*

Keywords— Kolam Patterns, Mathematical Visualization, Algorithmic Art, Eulerian Paths, Flutter App.

I. INTRODUCTION

Across human history, patterned forms have acted as a visual language through which cultures express belief systems, rituals, and collective knowledge. From the interlocking geometry of Celtic knotwork and Islamic interlace to the symbolic repetition found in Aztec carvings and South Indian Kolams, patterns encode meaning through structure, rhythm, and spatial logic. These traditions demonstrate that pattern-making is not merely decorative but a systematic way of thinking and reasoning. With the rise of computational tools, creative coding offers a new way to engage with such traditions—not as static subjects of study, but as living systems that can actively inform algorithmic creation.

Among these global traditions, **Pulli Kolams**—continuous loop drawings formed around dot grids—present a particularly rich foundation for computational exploration. Kolams are notable for their inherent mathematical properties, including symmetry, recursion, modularity, and single-stroke path construction. Rather than treating Kolams as artifacts to be replicated, this work approaches them as generative systems whose internal logic can be extended, reinterpreted, and interacted with through code.

Fig. 1. Popularity of Kolam in India

Fig. 2. Geometry in Kolam

Two complementary computational approaches guide this exploration:

1. **Recursive Construction:** Kolams are generated as uninterrupted looping paths using procedural drawing techniques. Implemented through rule-based traversal similar to turtle graphics, this method mirrors the hand-drawn process of Kolam creation. Comparable approaches can be found in Celtic knot construction, Islamic girih patterns, and macramé knot systems.

2. **Tiling-Based System:** Kolam designs are decomposed into modular units defined by curvature, orientation, and grid constraints. These units form a visual grammar that enables recombination while preserving flow and coherence. This method aligns with motif-driven traditions such as Kente weaving, Tatreef embroidery, and Truchet tiling.

This work positions Kolams as one such system and explores how their generative logic can be translated into interactive digital tools. Through open-source technologies and a web application, the project aims to create an environment where users can generate Kolam patterns while simultaneously understanding the mathematical rules that govern them.

II. LITERATURE REVIEW

Computational and mathematical studies on Kolam patterns have gained significant attention due to their rich structure, algorithmic nature, and deep cultural relevance. Early foundational work established Kolam as a formal mathematical system rather than merely a decorative folk art. Ascher [10] was among the first to rigorously document Kolam as a rule-based geometric tradition, highlighting its implicit use of symmetry, topology, and continuous curves.

2.1 Graph Theory and Discrete Geometry Approaches

Yanagisawa and Nagata [1] introduced a systematic design framework based on linear diagrams and exhaustive enumeration of Kolam configurations over small dot grids. Their analysis demonstrated that although billions of patterns are theoretically possible, only a very small fraction form valid single-loop Kolams, emphasizing the strict mathematical constraints governing Kolam construction.

Bharathi et al. [2] presented a deterministic computational model that represents Kolams as sequences of angular moves on a lattice. Each local movement (north, south, east, west, and turns) is encoded symbolically, enabling the entire Kolam loop to be captured as a finite string. This encoding also allows reverse engineering of hand-drawn Kolams into symbolic representations.

2.2 Tile-Based and Grammar-Based Systems

Raghavachary [3] demonstrated that all Kolam patterns can be generated using a finite set of 16 square tiles, each containing curved edge connections. By enforcing strict edge-matching rules, continuous closed loops emerge without loose ends. This tile-based perspective aligns Kolam generation with tiling theory, finite automata, and backtracking algorithms.

2.3 Recursive and Procedural Algorithms

Suressh [4] proposed both recursive turtle-based drawing systems and modular tiling approaches, showing how simple iterative rules can reproduce complex Kolam structures. These methods highlight the self-similar and rule-driven nature of Kolams and are particularly suitable for educational software and interactive applications.

2.4 Number-Theoretic and Parametric Constructions

Warren et al. [7] introduced Fibonacci-based Kolam generators, linking Kolam geometry with recursive sequences and growth patterns. Srinivasan [6] investigated Hridaya Kolams using modular arithmetic and sequencing techniques, providing executable MATLAB and Python implementations.

2.5 Topological and Knot-Theoretic Perspectives

Ishimoto [8] analyzed infinite Kolams as knot structures, revealing deep connections between Kolam loops and topological invariants. This viewpoint reinforces the idea that Kolams are fundamentally continuous, non-self-intersecting closed curves, which must satisfy Eulerian properties when represented as graphs.

2.6 Machine Learning Approaches

Sasithradevi et al. [5] developed KolamNetV2, an attention-based deep learning model for Kolam classification. While these works primarily focus on recognition rather than generation, they provide valuable insights into Kolam feature representations and stylistic variations.

III. METHODOLOGY

The research methodology involves two complementary approaches: (1) survey design for public perception analysis, and (2) mathematical formulation for algorithmic pattern generation.

3.1 Survey Design and Data Collection

A systematic Google Form survey was created to collect inputs about public perception and identification of Kolam. The form was shared on different online portals and accessed by a heterogeneous population group including:

- All professions (students, homemakers, professionals, etc.)
- All age groups (18–50 years)

The questionnaire contained a combination of multiple-choice and open-ended questions designed to measure the capability to distinguish between Kolam and modern art, familiarity with Kolam traditions, and other factors.

A total of **70 valid responses** were collected and securely stored for analysis. Respondent anonymity was preserved to ensure unbiased feedback.

3.2 Mathematical Formulations for Kolam Generation

The following five mathematical models were implemented for Kolam pattern generation:

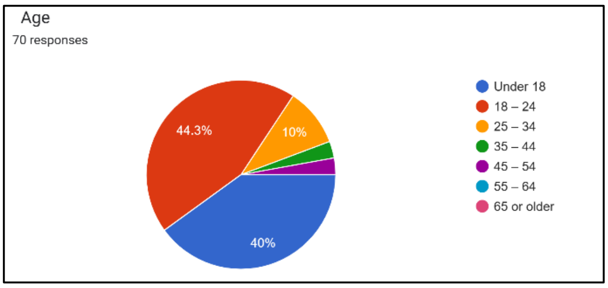

Fig. 3. Age Group contributed their views

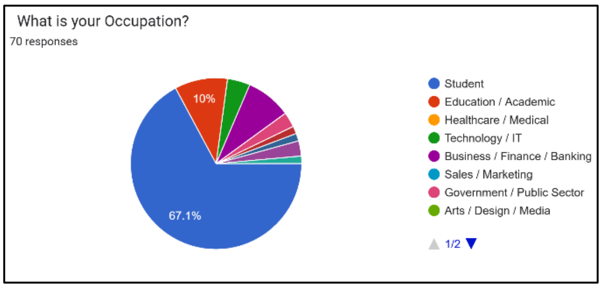

Fig. 4. Various Profession people contributed their views

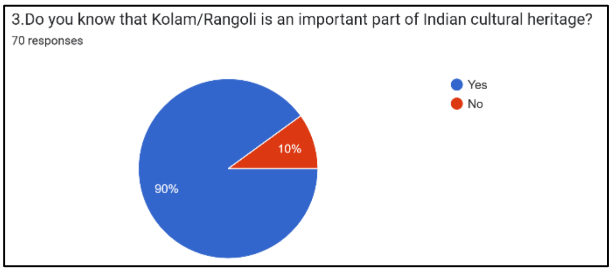

Fig. 5. Kolam Important part of Indian Culture?

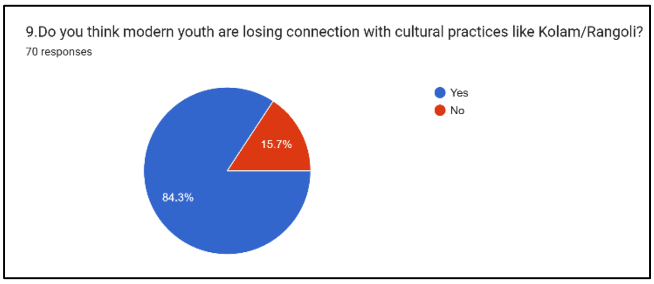

Fig. 6. Is modern youth losing cultural practices?

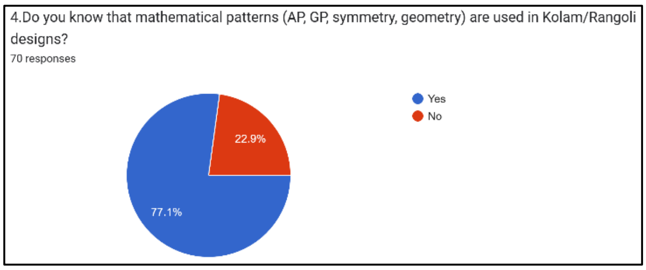

Fig. 7. Do you know that there is Mathematics in Kolam?

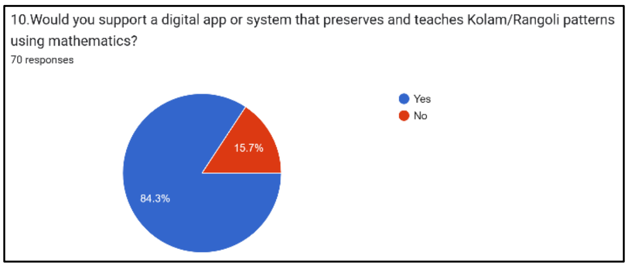

Fig. 8. Do you support digital system that preserves Kolam?

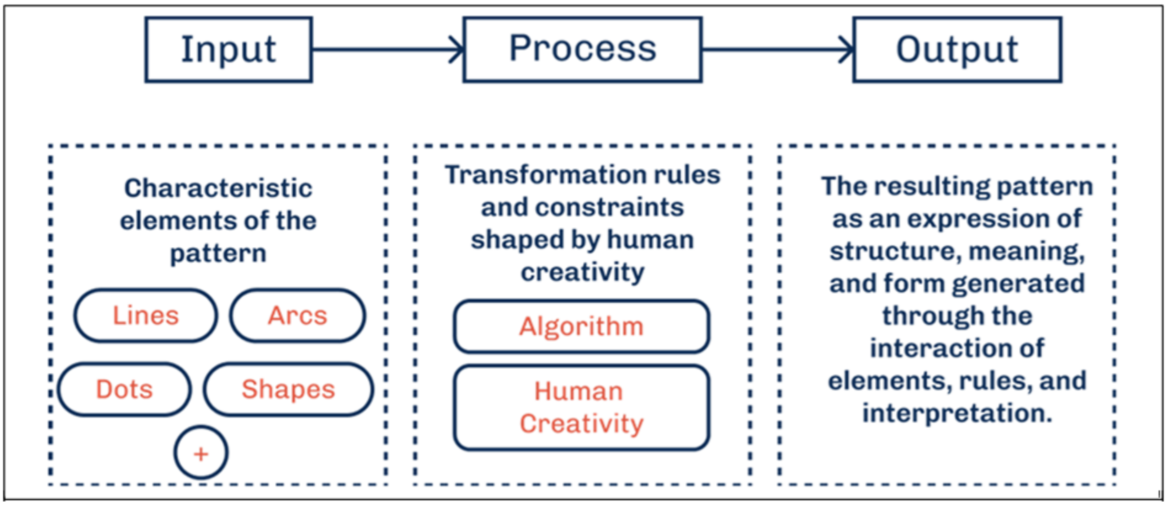

FIGURE 9: Input Output Process (IPO) Diagram representing a pattern as a system

IV. MATHEMATICAL FORMULATIONS AND RESULTS

4.1 Lissajous Curves for Symmetric Kolam Loops

User Parameters:

- Frequency along x-axis: A
- Frequency along y-axis: B
- Radius: R
- Center: (C_x, C_y)

Mathematical Formulation:

Lissajous curves are defined parametrically as:

$$x(t) = C_x + R\sin(At)$$
$$y(t) = C_y + R\cos(Bt)$$

where $A, B \in \mathbb{Z}^+$ control oscillation frequency, and $t \in [0, 2\pi k]$ ensures curve closure for integer k.

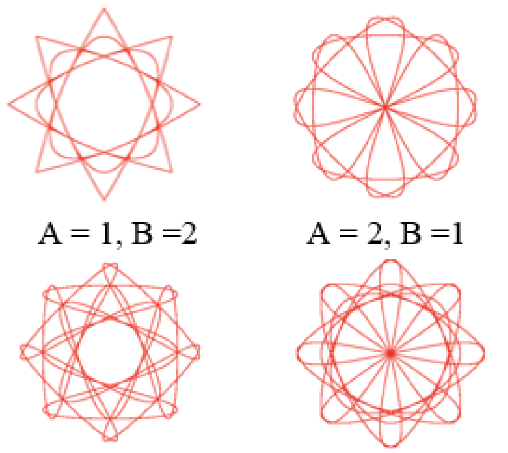

Fig. 10. Lissajous Curves

4.2 Petal Harmonics (Rose Curves for Floral Kolams)

User Parameters:

- Petal count: $n = 5$
- Harmonic depth: $d = 8$
- Radius: R

Mathematical Formulation:

The polar harmonic (rose) curve is defined as:

$$r(t) = R\cos\left(\frac{n}{d}t\right)$$

Converted to Cartesian coordinates:

$$x(t) = C_x + r(t)\cos(t)$$
$$y(t) = C_y + r(t)\sin(t)$$

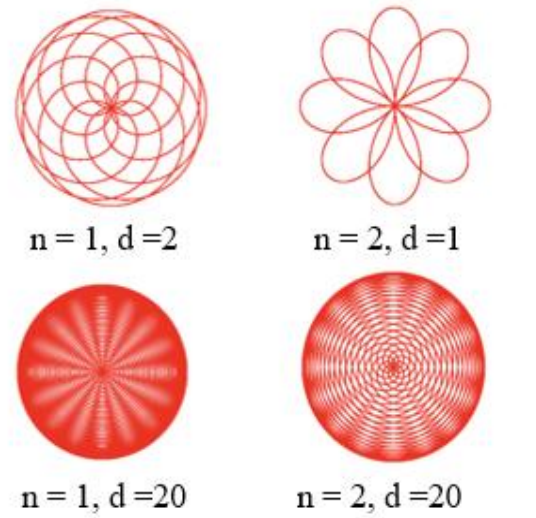

Fig. 11. Petal Harmonics

4.3 Twisted Knot Kolams (Torus-Knot Inspired Curves)

User Parameters:

- Twist factor: $p = 2$
- Lobe count: $q = 3$
- Radius: R

Mathematical Formulation:

A torus-knot–inspired parametric model is defined as:

$$r(t) = R\left(1 + \frac{1}{2}\cos(qt)\right)$$
$$x(t) = C_x + r(t)\cos(pt)$$
$$y(t) = C_y + r(t)\sin(pt)$$

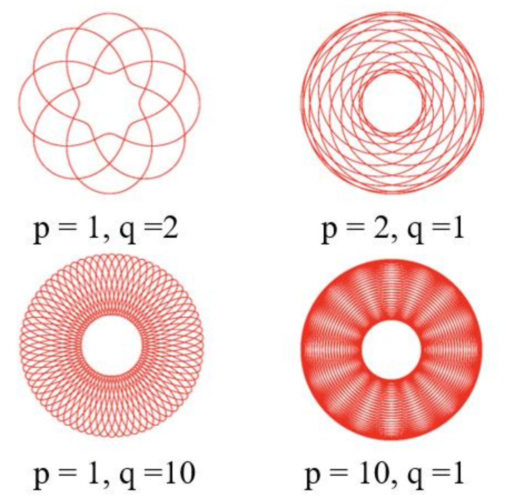

Fig. 12. Twisted Knot Kolams

4.4 Hridaya Kolam Using Modular Arithmetic

User Parameters:

- Number of points: $n = 20$
- Multiplication factor: $m = 3$
- Radius: R

Mathematical Formulation:

Evenly distributed points on a circle:

$$P_i = \left(C_x + R\cos\left(\frac{2\pi i}{n}\right), C_y + R\sin\left(\frac{2\pi i}{n}\right) \right)$$

Edges are formed via modular multiplication:

$$P_i \to P_{(i \cdot m) mod n}$$

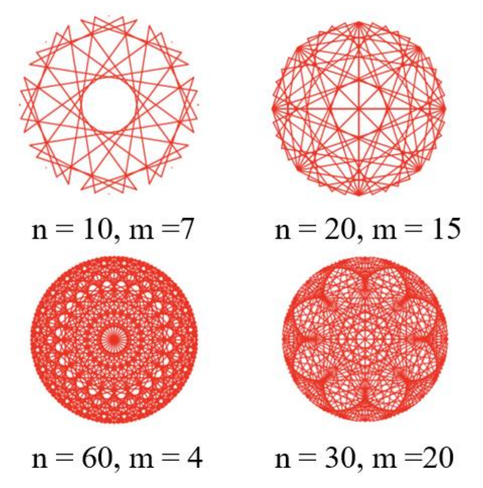

Fig. 13. Hridaya Kolam

4.5 Recursive Fractal Kolams

User Parameters:

- Recursion depth: $d = 3$
- Rotation angle: $\theta = 0^\circ$
- Base polygon sides: $N = 3$

Mathematical Formulation:

Vertices of a rotated polygon:

$$V_k = \left(C_x + R\cos\left(\frac{2\pi k}{N} + \theta\right),\ C_y + R\sin\left(\frac{2\pi k}{N} + \theta\right)\right)$$

Recursive definition:

$$F(d) = \bigcup_{k=1}^{N} F\,(d-1, V_k)$$

where s scales down at each recursion level.

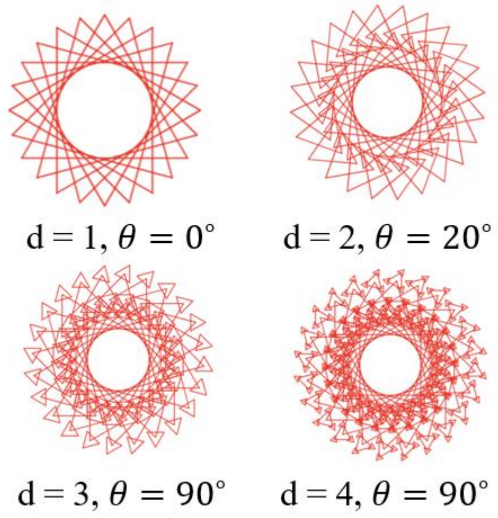

Fig. 14. Fractal Kolams

V. CONCLUSION

This study demonstrates that traditional Kolam patterns can be effectively modeled and generated using a unified mathematical framework based on parametric curves, harmonic functions, modular arithmetic, and recursive geometry. By controlling a small set of parameters, the proposed approach achieves precise symmetry, continuity, and structural complexity while preserving the aesthetic essence of classical Kolams.

The five mathematical models presented—Lissajous curves, rose curves, torus-knot inspired curves, modular arithmetic-based Hridaya Kolam, and recursive fractal Kolams—provide a comprehensive toolkit for algorithmic Kolam generation. The results confirm that culturally significant designs can be translated into efficient computational models, enabling real-time generation, creative exploration, and digital preservation.

The KolamGen application, built with Flutter, successfully demonstrates the practical implementation of these mathematical formulations, offering strong potential for applications in algorithmic art, education, and cultural computing.

FUTURE RESEARCH DIRECTIONS

Future research for KolamGen centers on the following directions:

1. **AI Pattern Synthesis:** Using GANs to generate novel Eulerian circuits and Kolam variations
2. **Cross-Cultural Extensions:** Blending Kolam symmetry with girih tiles or Celtic knots
3. **Immersive Visualization:** WebXR/VR for 3D collaborative drawing during festivals
4. **Gamified Education:** "Kolam puzzles" to teach modular arithmetic via reverse-engineering challenges
5. **Industrial Applications:** Textile design and CNC fabrication with guaranteed manufacturability
6. **Theoretical Frontiers:** Hyperbolic tessellations and quantum circuit analogs for exploring infinite pattern spaces

These directions will transform Kolam from cultural preservation into a computational creativity platform bridging folk mathematics with modern design industries.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this paper.

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