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From Temples to Algorithms: Exploring Fractal Geometry in Temple Architecture and Computational Practices

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Abstract

Fractal geometry, rooted in self-similarity and iterative progression, has long been embedded in Hindu temple architecture, centuries before the formal mathematical articulation of the concept. Despite this rich historical precedent, a notable decline in the integration of fractal geometry characterizes contemporary architectural landscapes, creating a significant void. This research bridges that gap by reinterpreting traditional fractal geometries, particularly the Shikhara of the Kandariya Mahadev Temple, through algorithmic modeling and user-centered analysis.

The study adopts a dual methodology: first, using Rhinoceros 3D with Grasshopper and GHPython, supported by AI-assisted scripting, to develop 15 fractal-based design prototypes; second, visualizing fractal complexity through Mandelbulb 3D and immersive VR environments in Unity. Empirical evaluation involved 100 participants in online surveys and 10 in VR-based offline studies, including architecture students, faculty, and professionals. While 80–100% of participants reported familiarity with fractals, 65–75% experienced challenges visualizing them on traditional screens. VR interaction significantly enhanced spatial understanding, with 75% reporting improved comprehension and an average aesthetic rating of 3.6 on Birkhoff's scale.

Findings reveal that fractal complexity enhances spatial engagement and symbolic resonance, offering promising avenues for reintegrating sacred geometries into contemporary practice. The study contributes both theoretical insight and a practical workflow for combining computational design with architectural heritage, laying a foundation for future explorations in generative and culturally rooted design.

Keywords: *Fractal Geometry, Temple Architecture, Computational Design, Grasshopper, Survey Analysis, Virtual Reality, AI-Assisted Design*

I. INTRODUCTION

Fractal geometry refers to self-similar shapes repeating at multiple scales. Benoît Mandelbrot coined "fractal" to describe natural patterns (coastlines, trees, crystals) that exhibit complex detail upon zooming (Mandelbrot, 1982). Unlike classical geometry, which uses fixed shapes, fractals "enrich and deepen" geometric possibilities (Bovill, 1996). The mathematical concept central to constructing fractal geometry is iteration, where diverse sets of rules, through perpetual repetition, endow the fractal shape with the essence of infinity. Geometrically, fractals inhabit an intriguing dimensional space, often falling between integer dimensions. They serve as compelling visual representations of dynamic systems, frequently mirroring the chaotic and unpredictable nature of reality itself. (Fig 1).

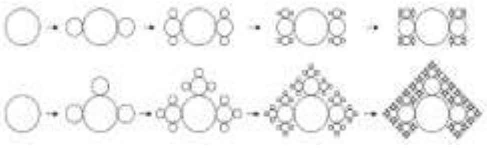

Fig. 1 Fractal pattern generation from a single circle using distinct iterative rules.
Source: (Md Rian et al., 2007)

In architecture, fractals allow designers to "reproduce complex patterns and irregular forms present in nature" (Sala, 2006). This fusion of natural order and design intuition has surfaced in history: for example, Gothic cathedrals and Baroque façades often show iterative detail akin to fractals.

1.1 Historical Context of Fractals in Hindu Temples

The profound connection between fractal geometry and architecture is nowhere more evident than in ancient Hindu temples. Ancient Indian mathematicians applied concepts of progression, iteration, and repetition to create stunning visual illusions (Trivedi, 1989). They keenly observed principles of creation, such as self-similarity, iteration, and repetition, in the natural world, and seamlessly incorporated these into their creative endeavors, most notably in the construction of their revered temples.

Remarkably, these temples were constructed long before the formal development of Fractal Theory (c. 3300–1300 BCE versus the 17th Century), yet they stand as timeless showcases of fractal-inspired architectural principles (Hardy, 2007). Hindu philosophy posits the cosmos as holonomic and self-replicating, with the temple serving as a symbolic conduit between the material and divine realms, its architectural layout meticulously replicated from the cosmic order, graphically depicted by the Vastu purusha mandala (Michell, 1988).

The construction techniques employed in Hindu temples involved principles such as projection, staggering, splitting, bursting of boundaries, expanding repetition, and progressive multiplication (Trivedi, 1989). (Fig 2). These methods, originating from ancient architectural texts known as Vastu-shastras, bear a striking resemblance to modern computer graphics procedures like discretization, fractalization, extensive recursion, and self-similar iterations. This suggests that ancient Vastu-shastras were, in essence, proto-algorithms, providing rule-based systems for generating complex forms.

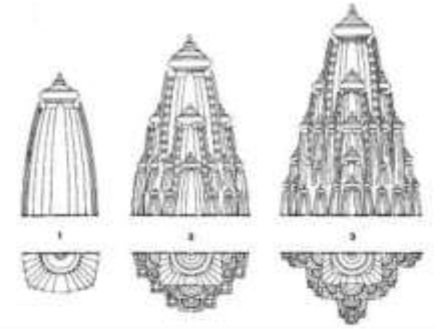

Fig. 2 Aedicular Progression
Source: Trivedi, 1993

1.2 Perception of Fractals in Contemporary Architecture

Fractal geometry in contemporary architecture serves multiple applications beyond mere aesthetics, reflecting its deep-rooted connection with natural systems and functional performance (Yıldız et al., 2023). The key aspects of fractal applications include biomimicry and ecological design, structural optimization, ornamentation and façade articulation, spatial complexity, and occupant wellbeing.

One of the most prominent applications is in biomimetic and environmental architecture, where fractal principles guide the design of structures that imitate natural patterns for optimized performance. For instance, Singapore's Supertree Grove employs fractal branching to enhance photovoltaic capture, ventilation, and microclimate regulation. Similarly, the Grand Egyptian Museum features fractal triangulated façades that control light and reflect cultural motifs. Structurally, fractals enable complex, load-responsive geometries, exemplified by Hansmeyer's "Subdivided Columns," where recursive subdivision reimagines classical forms as fractal ornamentation (Hansmeyer, 2010). In *Digital Grotesque*, Hansmeyer and Dillenburger further use fractal algorithms and 3D printing to fabricate immersive, microscopically detailed spaces (Hansmeyer & Dillenburger, 2013).

Fractals also contribute to occupant wellbeing and biophilic design. Studies show that environments incorporating fractal patterns, especially those with moderate fractal dimensions, can reduce stress and promote cognitive restoration (Joye, 2007). This psychological benefit encourages the integration of fractal geometry in healthcare, educational, and public spaces to enhance human experience.

Moreover, fractals have been explored in urban design and landscape architecture where recursive patterns create legible, hierarchical spatial networks, helping to organize circulation and ecological flows in complex environments.

1.3 Challenges and Decline in use

Despite the promise and exciting innovations, fractal geometry faces significant challenges that have limited its widespread adoption in architecture. The most pressing is constructability: fractal designs often involve highly intricate, recursive forms that are difficult and expensive to fabricate with conventional building methods (Bovill, 1996). While digital fabrication methods, such as 3D printing, have enabled projects like Hansmeyer's to materialize, these techniques remain costly and require specialized expertise, restricting their scalability.

Another challenge lies in the conceptual ambiguity and superficial usage of fractals. Many architects have applied fractal-like patterns decoratively without embracing the rigorous mathematical properties of fractals such as infinite recursion or strict self-similarity. This superficial application has led to skepticism within the architectural community, where fractals are sometimes viewed as ornamental embellishments lacking functional or environmental rationale.

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Over time, the popularity of fractals in architecture has also waned due to broader shifts in architectural discourse. The rise of minimalism, parametricism, and performance-driven design has shifted focus toward clean lines, optimized forms, and data-driven processes. Fractal geometry, with its ornate and visually complex language, often conflicts with these prevailing design paradigms, contributing to its marginalization.

However, interdisciplinary research in neuroscience and environmental psychology is gradually reviving interest in fractals by demonstrating their potential benefits to human wellbeing. This emerging evidence encourages a reconsideration of fractals not only as aesthetic devices but as meaningful contributors to therapeutic and sustainable architectural environments.

1.4 Technology Integration

The integration of computational design and artificial intelligence is increasingly important in contemporary architecture because it allows architects to manage complex geometries precisely while speeding up early-stage ideation and visualization (Li et al., 2024). Rhino 3D combined with Grasshopper offers a powerful parametric modeling platform where designers can create intricate fractal geometries using visual programming without needing advanced coding skills. Using GH Python scripting adds more customization and automation possibilities for fractal designs.

For fractal visualization, Mandelbulb 3D is a useful tool that provides access to many fractal formulas, supports visualizing fractal iterations, and allows exporting models to Rhino or other 3D software for further refinement. It is free to use and has been employed by artists like Jack Oliva Rendler and Julius Horsthuis who explore fractal geometries in their work.

Alongside these computational tools, generative AI models such as Midjourney, DALL·E, and Stable Diffusion enable fast conceptual rendering from simple text prompts (Shi et al., 2024). While these AI outputs offer rich visual variety, they often lack the geometric accuracy and parametric flexibility required for architectural design. However, recent advancements integrating AI into 3D modeling environments such as Rhino's Model Context Protocol and AI-driven plugins are creating workflows that can translate conceptual prompts into editable parametric models (Chen, 2024). This development simplifies the traditionally complex iterative design process.

II. RESEARCH STUDIES

The literature study has been developed through the analysis of existing research, organized around key thematic parameters: fractals in Hindu temples, fractals in computational design, and the mathematical basis of fractals and algorithms.

2.1 *Fractalization in Hindu Temple*

In Vāstu-śāstra, Hindu temple architecture is based on the Vāstupuruṣa Mandala, a square grid symbolizing cosmic order and the philosophy of Aham Brahmasmi, where part and whole reflect each other (Trivedi, 1989). This mandala is a conceptual framework representing the universe's structure through geometric abstraction, serving as an ideogram realized in the temple's form.

The cosmos is symbolized by a circle within a square grid (2D) or an ellipsoid within a cubic grid (3D). Discretizing curved forms into grids creates the temple's characteristic jagged outlines. Two main grids are used: the revered 64-square Manduka Mandala and the 81-square ceremonial grid. Each square (Pada) corresponds to a deity or cosmic force, with the central Brahma Padas housing the deity in the Garbhagriha. Surrounding layers include Devika Padas (gods), Manusha Padas (humans, including the Parikrama path), and Paishachika Padas (asuras).

In Plans

The temple's presiding deity, enshrined in the **Garbhagriha** or "womb chamber," serves as the conceptual and spatial core, symbolizing the cosmos from which the temple expands outward. This inner sanctum remains plain, in contrast to the increasingly ornate outer layers. A typical Hindu temple includes sequential spatial elements: the Ardha-mandapa (entrance porch), Mandapa (hall), Antarala (vestibule), and Garbhagriha (sanctum). In larger temples, these are elaborated with balconied windows, a Maha-mandapa (grand hall), and a circumambulatory path around the sanctum (Fig. 3).

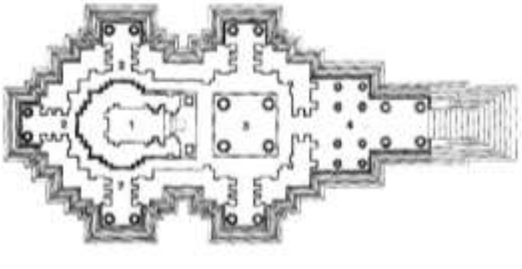

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Fig. 3 Plan of Kandariya Mahadev Temple showing key elements: 1. Garbhagriha, 2. Ambulatory Passage, 3. Mandapa, 4. Ardha-Mandapa.
Source: Trivedi, 1993

This spatial sequence follows a fractal logic, beginning with simple, recursive modules. The temple unfolds through progressively scaled elements: Mukhamandapa (entrance hall), Ardhamandapa (intermediate space), Maha Mandapa (main hall), and finally the Mulaprasada, which houses the sanctum. Each space emerges from the last through iterative geometric expansion, reflecting a fractal-based design progression (Fig. 4).

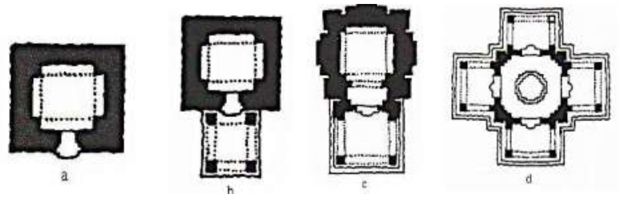

Fig. 4 a) Shrine only, b) Shrine with porch, c) Shrine with porch and antarala, d) Sarvatobhadra shrine with four entrances
Source: Hardy, Adam. The Temple Architecture of India

The temple plan evolved from a basic quadrangle to a square through iterative geometric refinements. As shown in Fig. 5, designs progressed from simple forms (a–e) to more complex projections at cardinal points. Figures f–i illustrate repeated recess patterns, while j–m depict merged configurations, each reflecting a disciplined axial logic and rule-based geometric development.

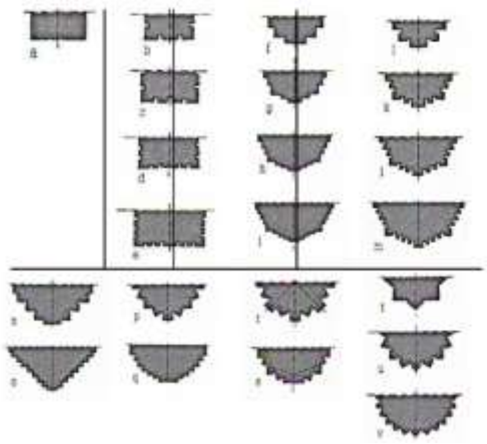

Fig 5 Evolution of temple plans: (a) Simple square, (b–e) with projections, (f–i) staggered without recesses, (j–m) staggered with recesses, (n–o) stepped diamond, (p–s) stellate forms with central projections, (t–v) unique and uniform rotated-square stellate plans.
Source: Hardy, Adam. The Temple Architecture of India

A prior study analyzed the fractalization of temples using the Box Counting Method, focusing on the Kandariya Mahadev Temple in Khajuraho, an exemplary model of fractal iteration in North Indian temple design. This iterative process was shaped by cosmological symbolism, sacred geometry, and proportional systems.

One hypothesis suggests the design originated from the Pitah Mandala, a nine-square grid, where each unit (pada) defines modular expansion. In the first iteration, the plan expands outward by one pada along each cardinal direction (Fig. 6a). The outer corners are then developed using meandering elements derived from the golden rectangle and quarter-pada units. These recursive additions generate a self-similar fractal pattern, particularly along the mandapa axis, culminating in the projection of the temple's entrance and overall completion of the form (Fig. 6b).

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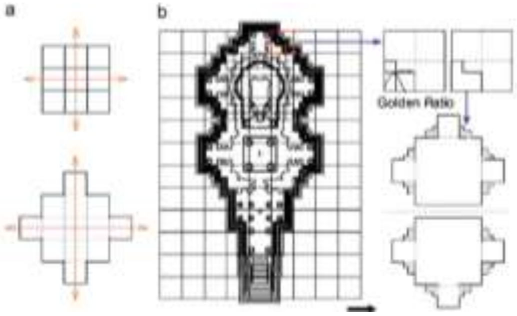

Fig. 6 (a) 9-square mandala and its cardinal expansion by one pada. (b) Plan of Kandariya Mahadev temple with fractal development showing golden ratio-based element formation from a pada and its recursive overlap to generate the final patterned plan.
Source: (Md Rian et al., 2007)

According to the second theory, the third iteration of the pitah mandala is a 36-square grid within the 100-square manduka chandita mandala, sharing the same coordinates. A circle touching the pitah mandala's corners symbolizes endless cycles of time, completion, and consciousness. Iterations are guided by gridlines, this circle, and a diagonal square whose corners touch the outer edges of the manduka chandita mandala. Each iteration starts at the intersection of the diagonal square's side and a previously iterated line, ending where the gridline meets the circle, and concludes at the diagonal square's corners (see Fig. 7). Extensions from the latest iterations mark the four cardinal directions, appearing as open verandas in the temple's architecture.

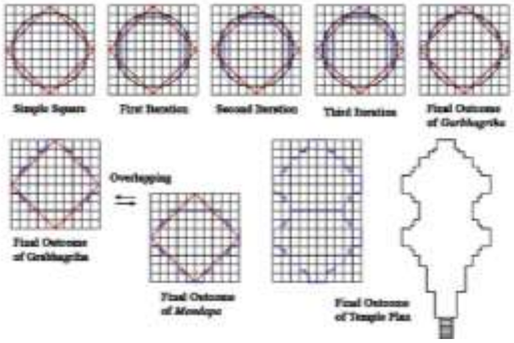

Fig 7 Geometric operations of mandalas and symbolic geometry in the Kandariya Mahadev temple plan.
Source: (Md Rian et al., 2007)

The fractal approach to the Kandariya Mahadev temple's plan creates a rough, irregular shape, with the central sanctuary mirroring the outer plan, reinforcing its fractal nature. Using 'Box-Counting Demonstration' software on a 50x70 mm plan image (80 pixels/cm) with grid sizes of 24, 12, 6, and 3 (Fig. 8), the analysis showed a fractal dimension of 1.70, indicating high roughness and detail. The graph's smooth straight line reflects uniform roughness. This detailed complexity is intentionally emphasized in the temple's structure, enhancing its overall texture (Md Rian et al., 2007).

Step	Grid size (S)	Marked boxes (N)	Log (S)	Log (N)
1	24	249	1.380	2.396
2	12	806	1.079	2.906
3	6	2554	0.778	3.407
4	3	8627	0.477	3.936

Fig. 8 Box counting operation of the plan of Kandariya Mahadev temple; (a) grid size 24; (b) grid size 12; (c) grid size 6; and (d) grid size three along with Graph and Table
Source: (Md Rian et al., 2007)

In Elevations

Fractals significantly shape temple elevations in three dimensions, reflecting self-similarity throughout the structure. While elevation styles vary regionally across India, certain divisions are nearly universal, including Pitha, Vedibandha, Jangha, Varandika, Sikhara, and Ghanta. Though Ghanta is part of the Shikhara, its distinct features set it apart. These elements are present in all Nagara-style temples, though names may differ regionally. The Pitha is the temple's base platform, made of repeating parts like Khura, Kumbha, Antarpatrika, Kalasha, and Kapotali, which form fractal patterns at different scales (Fig.

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9). Above it, the Vedibandha connects the Pitha to the Jangha and has similar shapes but with more decorative moldings (Fig. 9).

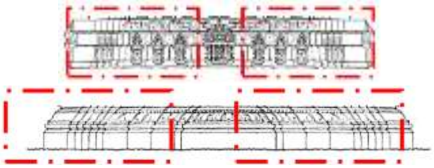

Fig. 9 Bottom: Pitha and Top: Vedibandha
Source: Hardy, Adam. The Temple Architecture of India

The Jangha is the walled part of the shrine, including the mandapas and Garbhagriha, shaped by fractals in its folds and decorations that repeat (Fig. 10). The Varandika forms the cornice, linking the Jangha and Sikhara with detailed designs (Fig. 10).

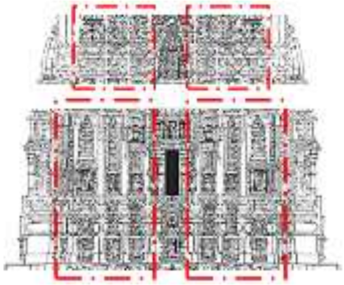

Fig. 10 Bottom: Jangha and Top: Varandika
Source: Hardy, Adam. The Temple Architecture of India

The Sikhara is the temple's main tower, made of layered peaks like a mountain range. The tallest peak is above the sanctum, with smaller peaks attached in complex designs (Fig. 11). The Ghanta is the highest part of the Sikhara, made of parts like Kantha (or Griva), Amlaka, Padmashirshaka, and Kalasha. Fractals mostly appear in the Amlaka, creating repeating rib patterns (Fig. 11).

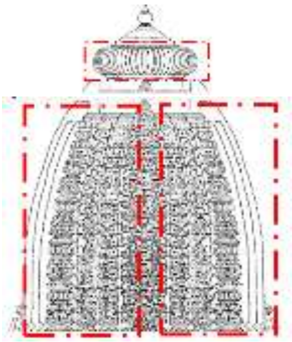

Fig. 11 Bottom: Sikhara and Top: Ghanta
Source: Hardy, Adam. The Temple Architecture of India

Hindu temple architecture draws inspiration from mountains as fractal models, with self-similar towers (shikharas) symbolizing ascending universes. The Kandariya Mahadev temple's towering shikhara represents Mount Kailash, the mythological abode of Lord Shiva. While all shikharas share a mountain-like form, they vary in repetition patterns, ornamentation, slopes, and geometry.

In Kandariya Mahadev, the main tower above the sanctuary is replicated on all four sides, continuing in smaller nested towers (Fig. 12a). This fractal repetition appears above the mandapa and arthamandapa, guiding the eye upward toward the cosmic axis (Fig. 12b). The tallest shikhara symbolizes liberation from the material world. The second tower is half the main tower's height, while smaller ones are one-third and one-fourth, aligning their peaks to form a unified ascent. This tower arrangement follows the golden sequence (Md Rian et al., 2007).

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Fig. 12 (a) Repetition of towers and elements in the shikhara; (b) whole shikhara form repeated within parts (red), with tower repetition above mandapas (green) guiding the eye upward to the main summit.
Source: (Md Rian et al., 2007)

To assess the uniformity and detail in the shikhara and its parts, the box-counting method was used to calculate fractal dimensions. The log-log plots yielded fractal dimensions of 1.87, indicating high and consistent fractal complexity (Md Rian et al., 2007). All data points formed straight lines on the graphs, confirming uniform detail across the entire shikhara and its self-similar components. (Fig. 14)

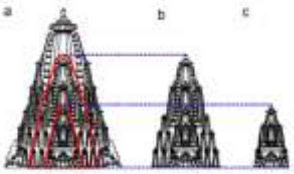
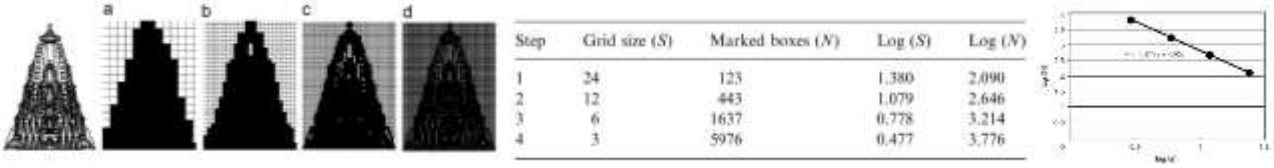


Fig. 13 Whole-in-part structure of the shikhara: (a) Entire shikhara above the sanctuary; (b) self-similar part; (c) smaller self-similar part.

Source: (Md Rian et al., 2007)



Step	Grid size (*S*)	Marked boxes (*N*)	Log (*S*)	Log (*N*)
1	24	123	1.380	2.090
2	12	443	1.079	2.646
3	6	1637	0.778	3.214
4	3	5976	0.477	3.776

Fig 14 Box-counting of shikhara (Fig. 34a): Extreme left—original; (a) grid size 24; (b) 12; (c) 6; (d) 3.
Source: (Md Rian et al., 2007)

This analysis reveals how intricate geometries are harmoniously composed within set parameters and quantified through algorithms. The temple serves as a prototype for exploring architectural possibilities using algorithm-based computational modeling.

2.2 *Aedicules in temples*

Early shrine designs were based on wooden prototypes, though no physical examples survive. Their forms can be reconstructed from 2nd-century BCE reliefs on Buddhist monuments, which depict the original monolithic, unitary structures. These early forms later became monumentalized in stone or brick, evolving into more complex, multi-aedicular compositions. Rather than fixed typologies, temple designs remained fluid older, simpler forms were absorbed into newer, more elaborate ones. This evolution occurred at both the overall compositional level and within specific architectural elements (aedicular components), with earlier phases persistently influencing later ones.

Temples adopted a three-dimensional, multi-aedicular shape, where several aedicules appeared integrated into the temple body (Fig. 15). Techniques such as projection, staggering, boundary extension, repetition, and gradual multiplication contributed not only to structural growth but also to a dynamic sense of motion. Aedicules were often arranged through successive projection, one emerging from another in a chain of diminishing forms. Sometimes the entire shrine itself became a component atop a larger composite form, or it could be embedded and extended along the cardinal axes.

This layering gave the temple a sense of expansion and transformation, where individual parts reflected multiple stages of evolution. Over time, traditions emerged through this recursive process with new types forming by extending and reconfiguring earlier ones

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Fig. 15 Conceptually embedded aedicules in a Nagara temple.
Source: Adam Hardy. Indian Temple Typologies

2.3 Recursive and Subdivision Methodology

Michael Hansmeyer's work represents a seminal contribution to recursive subdivision in architecture (Hansmeyer, 2010). Projects like Subdivided Columns and Digital Grotesque use algorithmic logic to create extremely intricate geometries from simple base forms. In Subdivided Columns, Hansmeyer applied a series of subdivision rules to abstract classical columns, producing forms with millions of facets fabricated by stacking CNC-cut or laser-cut sheets. Digital Grotesque I and II extended this method to spatial enclosures with 3D-printed sandstone grottos that embody recursive branching and folding (Hansmeyer & Dillenburger, 2013).

His process begins with a semantically tagged base geometry, followed by iterative recursive subdivision rules that vary locally, allowing heterogeneity across a single form. The subdivision is not purely fractal since iterations differ to introduce controlled complexity. Each stage undergoes mesh refinement to remove errors and meet fabrication constraints like minimum feature sizes. The result is an ornamented surface that appears chaotic but is rooted in deterministic processes.

Hansmeyer used custom scripts in platforms such as Maya, with MEL scripting, and likely Python or C++ for handling high-density meshes. Fabrication involved CNC milling and binder-jet 3D printing with sand for full-scale works. The Digital Grotesque pavilions consist of large "smart bricks," each 3D printed with embedded joints and structural detailing.

Challenges in the workflow included managing computational load due to complex meshes, fabrication tolerances, and balancing algorithmic control with aesthetic emergence. These issues reflect a broader tension in generative architecture between predictability and surprise.

Hansmeyer's work conceptually aligns with the recursive fractal logic explored here. His forms show nested, self-similar patterns guided by symbolic or formal logic.

Fig. 16 Subdivided Columns by Michael Hansmeyer.
Source: Michael Hansmeyer - Subdivided Columns

III. RESEARCH METHODOLOGY

This research conducts a qualitative analysis that goes beyond theory to explore the relationship between fractal geometry and temple architecture. It focuses on practical computational design by generating prototypes to understand and visualize how fractals integrate into temple elements. The study follows two main approaches:

First, using Rhinoceros 3D with Grasshopper and GH Python enhanced by AI workflows, the research aims to regenerate a temple element, the Shikhara. Prototypes replicate existing fractal patterns and explore new variations. An online survey using Likert scale questionnaires gathers participants awareness of fractal geometry and their feedback on the prototypes.

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Second, fractal geometry is explored through visualization software, mainly Mandelbulb 3D, and Virtual Reality using Unity. An offline survey based on aesthetic scale analysis collects participant responses to fractal-based geometry experienced in VR, focusing on aesthetics and emotional impact.

The goal is to assess awareness, compare perspectives, and evaluate aesthetic preferences, providing a comprehensive understanding of fractals in contemporary architectural design.

3.1 First Approach

The selection focused on two key aspects:

1. **Temple Element**: The Shikhara was chosen for regeneration due to its high level of visual fractal repetition observed in the Kandariya Mahadev Temple, as identified through the Box Count Method in the literature review. The Shikhara, a prominent tower symbolizing a mountain peak, features self-similar forms that reflect cosmic principles in Hindu philosophy. Its layered, recursive design made it ideal for computational simulation using fractal algorithms.
2. **Software**: Rhinoceros 3D was selected due to its wide use in parametric modeling and the researcher's familiarity. Grasshopper was used to generate fractal-based scripts and prototypes. The process was further explored using AI tools to simplify and enhance the modeling workflow. This enabled the creation of multiple prototypes for immersive visual surveys, gathering feedback from architecture students and educators on fractal forms.

After selecting the Shikhara, the modeling began in Rhinoceros 3D with a base *aedicule* geometry. Grasshopper scripts were developed to apply recursive fractal logic by repeating elements within themselves. Insights from the initial reconstruction informed the next phase, which used Rhino MCP to explore AI-assisted generation of the Shikhara.

Using Grasshopper

Based on the aedicule strategy identified in the literature review, a basic aedicule model was developed in Rhino.

Fig. 17 Aedicule used as base geometry in Rhino.

Using Looping: The script is a recursive geometry generation system developed using the Anemone plugin in Grasshopper, which facilitates iterative looping. The process begins with the creation of a base rectangle on the XY plane, with adjustable dimensions controlled by numeric sliders. This rectangle is subdivided and analyzed through components such as Explode, Curve Middle, and Construct Domain, which extract geometric features like segments and midpoints to inform the recursive logic.

Central to the workflow is the Anemone Fast Loop, which executes a user-defined number of recursive iterations using Fast Loop Start and Fast Loop End components. Within each iteration, a Cluster applies transformation rules such as scaling, subdivision, or orientation changes to the input geometry. The modified geometry is then looped back, generating increasingly complex outputs with each cycle.

Following the iterations, the generated forms are merged and passed through Box Morph, a component that maps geometry from a reference box to a target bounding box (Fig 18). This step spatially deploys the recursively generated form possibly a modular unit like an aedicule into its final configuration. The recursive logic and modular transformations reflect principles of fractal geometry and hierarchical temple architecture, making the script ideal for symbolic spatial systems.

Throughout the loop process, individual box geometries were baked at each iteration, resulting in a series of fifteen distinct prototypes, each derived from variations in recursive square placement.

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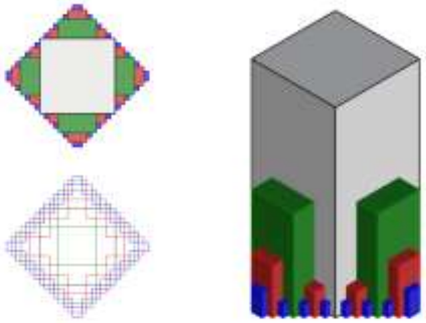

Fig. 18 Iterative development using Grasshopper

For the box morphing process, the aedicule geometry was used as the base reference (Fig. 21). Figure 18 illustrates the iterative development of one selected pattern from the fifteen generated: the grey form represents the initial geometry, followed by green for the first iteration, red for the second, and blue for the third. This process can be extended further through additional iterations. The final outputs were then baked into Rhino for further use.

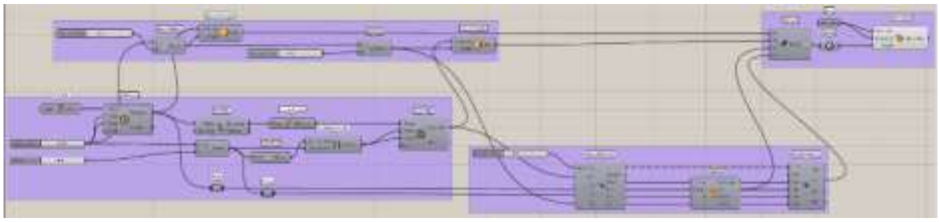

Fig. 19 Grasshopper script developed using Loops

Using GH Python script with AI: The script was generated using Anthropic's Claude Sonnet, although any other large language model (LLM) could be employed. Initially, the design intent was conveyed through a combination of images and text. After minor refinements, the model produced a complete and functional script. The main objective was to replicate, using GHPython, the operations previously constructed manually in Grasshopper through looping components (Fig. 22).

The process followed this sequence: graphical and textual information was provided to ChatGPT or another LLM to generate a base Python script for 3D geometry. This code was then imported into Grasshopper, where further adjustments and visualizations were made. Subsequently, the aedicule was box-morphed using the same methodology applied in the recursive looping script.

In Claude's workflow, the GHPython script creates a recursive arrangement of boxes within Rhino/Grasshopper. Each generation of boxes is scaled down and extends outward from its parent while remaining half-embedded within it. Starting from a central base box, the script computes four new positions that were: top, right, bottom, and left for smaller child boxes during each iteration. These boxes intersect the parent box by half their volume, creating a controlled, fractal-like spatial expansion (Fig. 20). To ensure clarity and reduce clutter, a filtering mechanism removes any boxes that are fully enclosed within a parent. The final output is a visually dynamic structure composed only of partially visible boxes, making it particularly suitable for architectural experimentation in recursive design and pattern development.

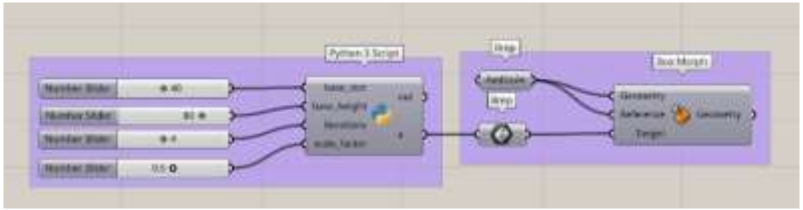

Fig. 20 GH python script developed using AI

Comparison of the workflows: Both workflows yield similar results, but AI-generated GH Python scripts are faster and more compact, while using Grasshopper alone requires prior knowledge.

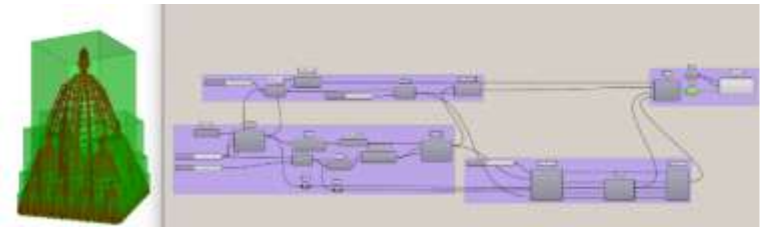

Fig. 21 Script workflow using loops

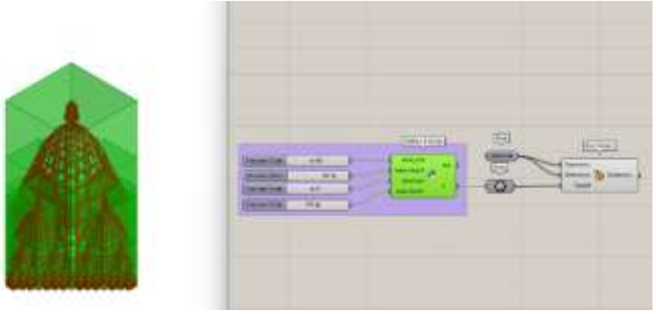

Fig. 22 Script workflow using AI in GH python

Final Product

The two scripts produced 15 prototypes (Fig. 23) using three methods. Incorporating AI in the second method made the workflow easier and more experimental.

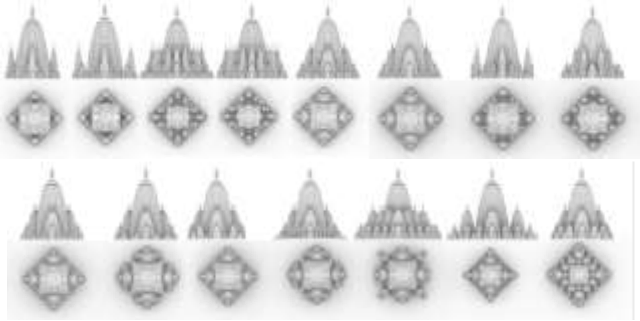

Fig. 23 Fifteen iterations in First Approach

3.2 Second Approach: Mandelbulb 3d

The online survey revealed that participants struggled to visualize and integrate fractals into their designs mainly due to limited knowledge of suitable software and platforms. To address this, our second approach focused on using fractal-based software for visualization and selecting an effective presentation platform. We conceptualized fractal structures using combined formulas in Mandelbulb 3D, then refined them in Rhinoceros 3D for precision. The final models were imported into visualization platforms to explore connections between fractal geometry and contemporary design through comprehensive analysis.

Module 01

We began in Mandelbulb 3D by selecting formulas with architectural qualities, including Koch cube, OctKoch, SierpHilbert, and ATetraVS. These were combined to create four visual modules: three smaller structures and one complex base module. The first module used the double OctKoch formula, producing striking visuals with four iterations at a scale of 2.225 for Formula 01 and one iteration at scale 2 for Formula 02. Figures 24 and 25 illustrate these captivating shapes and textures from multiple perspectives, showcasing the complexity achieved through this approach.

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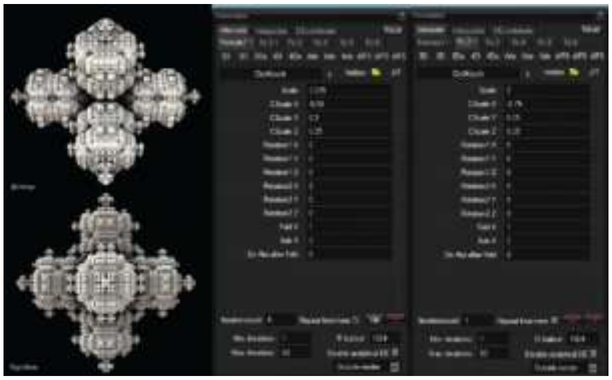

Fig. 24 Module 01 specifications from the software

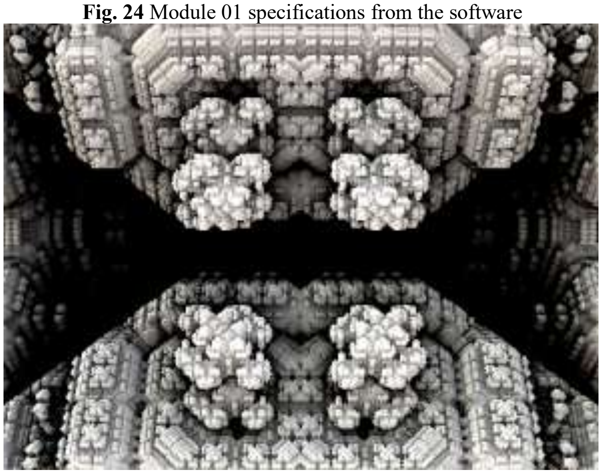

Fig. 25 Visualisation of Module 01 in Mandelbulb 3D

Module 02

In Module 02, we used the OctKoch and SierpHilbert formulas to add diversity and complexity to our visuals. Specifically, Formula 05 underwent four iterations at a scale of 2, while Formula 02 had one iteration at a scale of 3. This combination produced a compelling fusion of shapes and patterns, as shown in Figure 26.

Figure 26 details the parameters and inputs of these formulas, providing a clear blueprint of our process in Mandelbulb 3D. Figure 27 presents an immersive visual overview of the results, highlighting the unique aesthetic possibilities created by the interplay of these mathematical formulas within the Mandelbulb 3D environment.

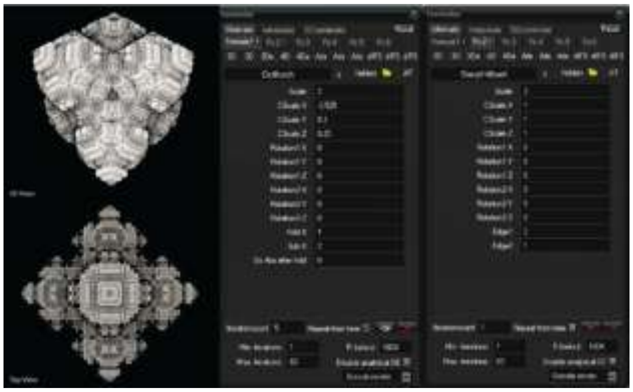

Fig. 26 Module 02 specifications

Fig. 27 Visualisation of Module 02 in Mandelbulb 3D

Module 03

In Module 03, we applied the Koch_cube, OctKoch, and _SinhY formulas to enrich our geometric palette. Formula 01 underwent two iterations at a scale of 0.55, Formula 02 had one iteration at a scale of 2, and Formula 03 had one iteration with a multiplication factor of -2. This combination produced visually intricate structures.

Figure 28 documents the detailed configurations and inputs of these formulas, outlining the creative decisions behind Module 03. Figure 29 showcases the resulting visuals in Mandelbulb 3D. The interplay of iterations, scales, and multiplication factors created a dynamic composition, highlighting the aesthetic potential of mathematical formulas in this fractal environment.

Fig. 28 Module 03 specifications

Fig. 29 Visualisation of Module 03 in Mandelbulb 3D

Module 04

In Module 04, we combined the ATetraVS formula by Dain Bramage with Koch_cube and OctKoch, resulting in a visually intricate hexagonal fractal composition, as shown in Figure 30. ATetraVS was key to the complex geometry of the structure. Figure 30 details the parameters and inputs used, highlighting the creative decisions behind the module.

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The visual outcomes were achieved by configuring Formula 01 with five iterations at a scale of -2, Formula 02 with one iteration at a scale of 1, and Formula 03 with one iteration at a scale of 2. These variations enabled the generation of a compelling hexagonal fractal within Mandelbulb 3D. The synergy between the formulas and careful adjustment of iterations and scales produced a complex composition that demonstrates diverse temple-inspired aesthetics through mathematical formulas.

Fig 30 Module 04 Specifications

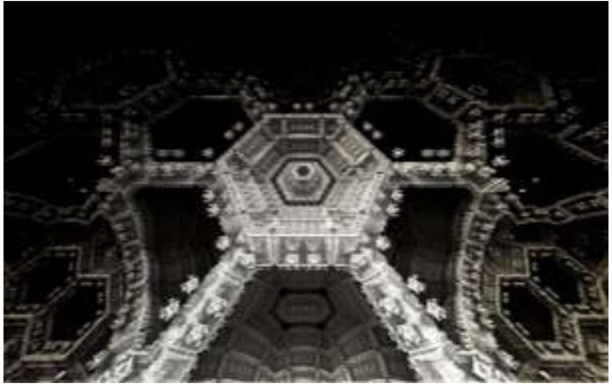

Fig 31 Visualisation of Module 04 in Mandelbulb 3D

Final Product

The four modules generated were exported into Rhinoceros 3D and combined into a unified fractal-based architectural structure. The main objective was to design a pavilion resembling a temple that immerses participants in the complexity of fractal geometry, enabling them to experience and visualize these forms firsthand. The central pavilion consists of two large-scale shells derived from Module 04, while Modules 01, 02, and 03 are integrated as smaller display elements. These were strategically arranged within the pavilion to enhance the overall visual impact and encourage exploration (see Fig 32). This design aims to provide an engaging, educational environment that deepens participants' understanding and appreciation of fractal geometries and their architectural potential.

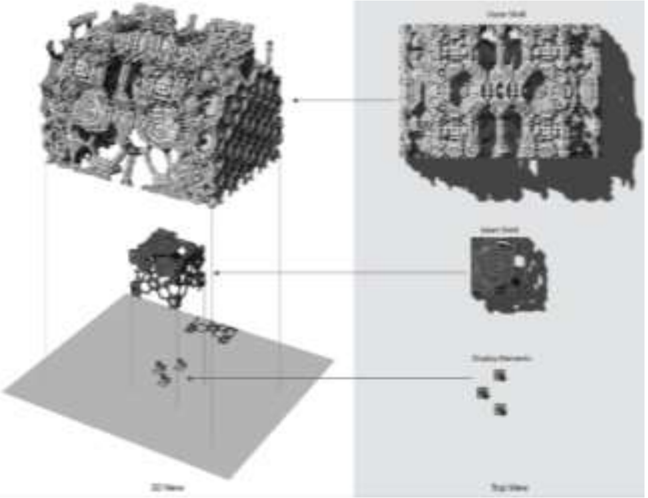

Fig. 32 Fractal-based structure assembled in Rhinoceros 3D

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IV. ANALYSIS & RESULTS

The analysis of both approaches was conducted through surveys of architecture students and faculty to assess their understanding and perspectives on fractals:

4.1 Analysis Approach: Part 1

Process

1. For our initial approach, we used an online questionnaire to assess awareness of fractals and gather opinions on selected prototypes regarding order and complexity. The process involved:

1. Selection of the Geometry:

- From 15 initial prototypes, we shortlisted 5 diverse geometries for the survey (Fig 33).
- The chosen forms varied in fractal patterns and their resemblance to the Kandariya Mahadev Shikhara.

Special attention was given to the fractal characteristics during the selection process.

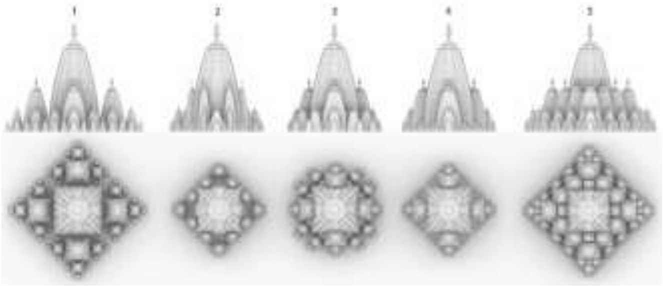

Fig. 33 Shortlisted Prototypes

2. Participant Criteria:

- The survey targeted architecture students, faculty, and practicing architects.
- This group was chosen for their architectural background, ensuring a nuanced understanding of fractals.
- Participants included second- and third-year architecture students, temple architecture and history scholars, heritage architects, and computational designers.
- Their technological proficiency facilitated a smooth online survey experience.

3. Survey Questionnaire:

- The online survey included two distinct questionnaires tailored to different respondent groups.
- One questionnaire, designed for architecture students, contained 12 general questions on fractal geometry.
- The second, aimed at faculty and architects, featured 16 more advanced questions on fractal geometry.
- Both questionnaires were structured with an initial section on personal information and awareness of fractal geometry in architecture, followed by Likert scale questions evaluating the five shortlisted geometries based on order and complexity.

Result

The analysis of the initial survey yielded the following results:

1. **Survey Response:** A total of 100 participants completed the survey, including 80 architectural students and 20 faculty members and architects. The survey assessed participants' understanding of fractal geometries, with graphical representations shown in Figures 34 and 35. A comparison between students' and architects' opinions was made using a Likert scale questionnaire, visualized in a bar graph (Fig. 36). This graph highlights the geometries selected based on perceived order and complexity, with percentages indicating average preferences across all participants.

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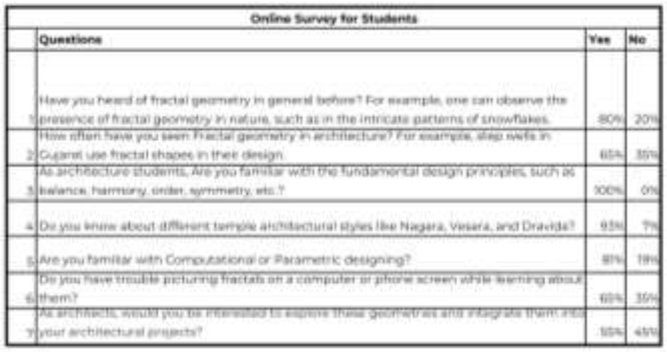
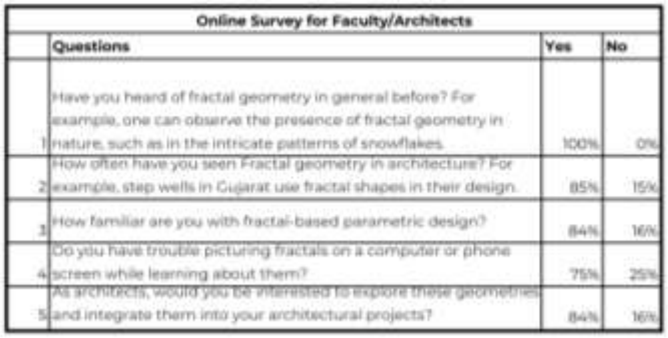


Online Survey for Students

	Questions	Yes	No
1	Have you heard of fractal geometry in general before? For example, one can observe the presence of fractal geometry in nature, such as in the intricate patterns of snowflakes.	80%	20%
2	How often have you seen Fractal geometry in architecture? For example, step wells in Gujarat use fractal shapes in their design.	65%	35%
3	As architecture students, Are you familiar with the fundamental design principles, such as balance, harmony, order, symmetry, etc.?	100%	0%
4	Do you know about different temple architectural styles like Nagara, Vesara, and Dravida?	93%	7%
5	Are you familiar with Computational or Parametric designing?	81%	19%
6	Do you have trouble picturing fractals on a computer or phone screen while learning about them?	65%	35%
7	As architects, would you be interested to explore these geometries and integrate them into your architectural projects?	55%	45%

Fig 34 Average response by students on general questions



Online Survey for Faculty/Architects

	Questions	Yes	No
1	Have you heard of fractal geometry in general before? For example, one can observe the presence of fractal geometry in nature, such as in the intricate patterns of snowflakes.	100%	0%
2	How often have you seen Fractal geometry in architecture? For example, step wells in Gujarat use fractal shapes in their design.	85%	15%
3	How familiar are you with fractal-based parametric design?	84%	16%
4	Do you have trouble picturing fractals on a computer or phone screen while learning about them?	75%	25%
5	As architects, would you be interested to explore these geometries and integrate them into your architectural projects?	84%	16%

Fig. 35 Average response by Faculties/ Architects on general questions

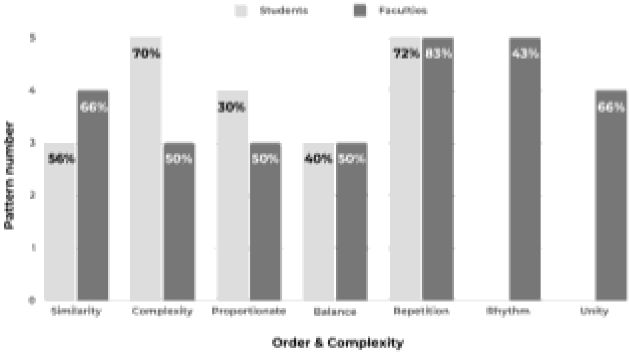


Fig. 36 Comparison of Likert scale responses by participant category

2. **Findings:** The study found that 80% to 100% of participants were familiar with fractal geometry, though 65% to 75% had difficulty comprehending and visualizing it on screens. Additionally, 55% to 84% expressed interest in using fractals in their design work if they had better knowledge of the tools and techniques.

In the general questionnaire, students preferred applying fractals during the conceptual stage, particularly for form and façade design. Faculty and architects emphasized its potential in the design development stage, especially when determining the height of the Shikhara in temple construction. Notably, 83% of faculty and architect respondents identified Rhinoceros 3D as the most suitable software for creating fractal-based forms.

Likert scale responses revealed a gap in understanding between students and faculty, indicating a need for more education on fractal applications. Participants acknowledged the value of fractals in interpreting and designing complex temple geometries and recognized their potential in modern architectural contexts.

In conclusion, the survey suggests that with greater access to computational tools and visualization platforms, fractal geometry can drive design innovation from reimagining traditional temples to integrating complex geometry into contemporary architecture.

4.2 Analysis Approach: Part 2

Process

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To evaluate the effectiveness of the chosen platform for visualizing fractal geometries and aiding form exploration, the generated structure was presented through an offline survey. This approach addressed challenges identified in the online survey, where participants struggled to grasp fractals on screens. The process followed these key steps:

1. Selection of VR Platform:

- Virtual Reality (VR) was chosen as the ideal medium to assess emotional response and understanding in a fractal-based environment.
- Unity was selected for its accessibility and user-friendly interface.
- The VR space was designed to resemble an ancient temple under a night sky, creating an enclosed ambiance with integrated display elements (see Fig. 37).
- Participants were in a static viewing mode and were able to look around but not move but they can interact with three display structures. The model was mirrored below to evoke a floating sensation and minimize confusion with VR controls.

Fig. 37 Setting the environment in Unity

1. **Participant Criteria:**

- Participants were selected to ensure diverse perspectives across varying levels of architectural understanding.
- The group included two faculty members/architects specializing in temple architecture, two fifth-year, two fourth-year, and two third-year architecture students, along with two VR visualizers from non-architectural backgrounds for the offline VR survey.

2. **Survey Questionnaire:**

- Participants were required to complete a consent form before beginning the survey.
- A brief onboarding tutorial introduced them to the VR interface.
- Each participant had 2–5 minutes to explore the environment, followed by a post-survey questionnaire.
- The survey used a Likert scale with 12 questions focused on order, complexity, and emotional response, aiming to derive an aesthetic scale based on Birkhoff's model.

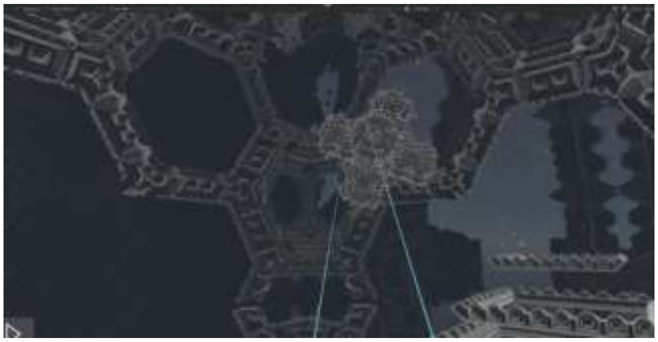

Fig. 38 Participants interacting inside Unity

Result

The analysis of the second survey provided valuable insights:

1. Survey Response: A total of ten participants completed the survey, comprising six architectural students, two teaching faculty/architects, and two individuals without an architectural background. The responses were analyzed using comparative graphs illustrating differences between participant categories, along with average ratings of order and complexity (see Figs. 39 and 40). An aesthetic scale was calculated using Birkhoff's aesthetic scale, incorporating emotional response metrics.

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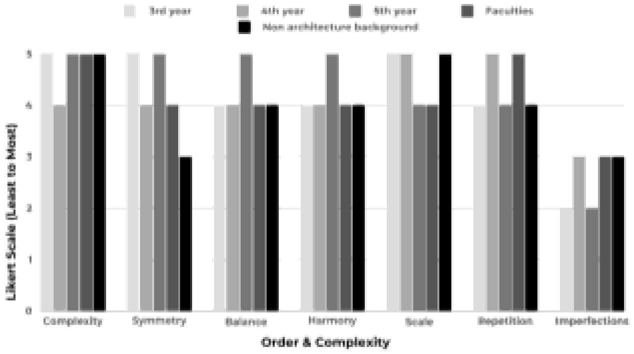

Fig. 39 Comparative Likert Scale Responses by Participant Category

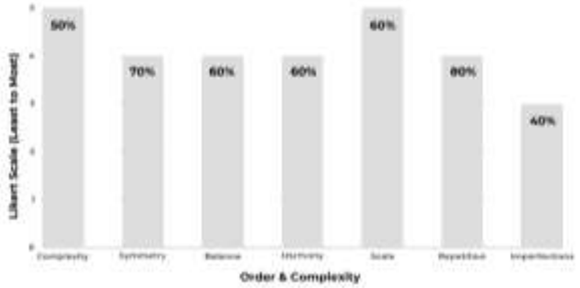

Fig. 40 Average Participant Responses on Likert Scale

2. Aesthetic Scale Calculation: From Based on data presented in Fig. 40, the average values for order and complexity were applied to Birkhoff's aesthetic scale. This scale involves three stages: initial attention, the aesthetic measure (feeling of value), and the recognition of harmony, symmetry, or order. Complexity (C) was quantified as the sum of exertions multiplied by their frequency. Order (O) was calculated as the sum of formal associations multiplied by their frequency. The aesthetic measure (M) was computed using the formula:

$$M = (\sum O \text{ x } n) / (\sum C \text{ x } n),$$

   Meanwhile, the value of $O= (20-3) = 18$, $C= 5$, and $n= 10$, resulting in an aesthetic measure (M) of 3.6.

3. Findings: Results indicated that 75% of participants reported improved understanding of fractal geometry through VR visualization, while 60% found the experience visually appealing. The calculated aesthetic measure of 3.6 corresponds to a moderate-to-high level of aesthetic appreciation. Approximately 65% of participants reported strong emotional engagement, describing the structure with terms such as *dystopian*, *peaceful*, *fascinating*, and *surreal*. One professional participant noted similarities to the ceiling of the Dilwara Jain Temple. Participants suggested enhancements including greater interactivity and navigability within the VR environment. Notably, many emphasized a significant difference between standard screen visualization and immersive VR experiences.

V. CONCLUSION

This research demonstrates the potential for reintroducing fractal geometry into contemporary architectural practice by integrating traditional temple design with computational methods. Through a combined methodology of AI-assisted parametric modeling and immersive virtual reality visualization, the study presents a structured framework for generating and evaluating fractal-based architectural forms.

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The findings emphasize three key insights. First, although awareness of fractal geometry is high among architecture students and professionals (80–100%), a significant number (65–75%) face challenges in understanding fractal patterns through conventional screens. Second, incorporating AI into Grasshopper workflows effectively simplifies the creation of complex recursive geometries, making advanced design processes more accessible. Third, VR-based visualization notably enhances spatial comprehension and emotional engagement, with 75% of participants reporting improved understanding. An average aesthetic rating of 3.6 on Birkhoff's scale further supports the visual and experiential appeal of fractal designs.

Participant feedback reflects emotional responses ranging from tranquillity to fascination, suggesting that fractal forms not only offer formal richness but also foster meaningful spatial experiences. This underscores the value of self-similar geometry in creating environments that resonate with human perception and emotion.

The research offers a method for extracting fractal logic from Hindu temple architecture and adapting it using modern design tools. By combining symbolic tradition with computational innovation, it provides a foundation for integrating cultural geometry into architectural experimentation and practice.

Future Directions

Several pathways for future exploration emerge from this study:

Expanded Computational Integration: Advancing AI-driven design workflows, particularly with large language models, could support automated generation and refinement of fractal forms.

Multi-Sensory VR Environments: Introducing haptic feedback and spatial audio into VR could enhance user immersion and understanding of fractal space.

Performance-Based Fractal Design: Applying fractal principles to optimize environmental performance, structural efficiency, and spatial clarity may lead to more functional and responsive designs.

Cross-Cultural Analysis: Investigating fractal patterns in other architectural traditions may reveal shared symbolic strategies and expand the scope of cultural design.

Fabrication and Construction: Developing buildable methods for fractal-based designs, addressing real-world constraints of materials, structure, and cost, is critical to implementation.

Longitudinal User Studies: Long-term research into how users experience and respond to fractal architecture can inform future design standards grounded in well-being.

In conclusion, this work bridges ancient geometric insight with emerging technology, proposing a new direction for architectural design rooted in tradition yet open to innovation.

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