The Visual Computer

Hindu temples: models of a fractal universe

Kirti Trivedi

Industrial Design Centre, Indian Institute of Technology, Powai, Bombay 400 076, India

Hindu philosophy views the cosmos to be holonomic and self-similar in nature. According to ancient architectural tradition, Hindu temples are symbols of models of the cosmos and their form represents the cosmos symbolically.

The procedures and methods used in the construction of Hindu temples bear a striking resemblance to the procedures of computer graphics, including discretization, fractalization and extensive use of recursive procedures, including self-similar iteration. The instructions given in ancient Vastu shastras (texts on architecture) work like general programmes to generate various types of temples.

This paper is an attempt to draw attention to the similarities between the procedures and resulting forms in computer graphics and Hindu temple architecture and to explain the relationship that exists between the form of the temple and the concepts of Hindu philosophy. It is proposed that Hindu temples may be viewed as three-dimensional fractal models and that the use of fractal geometry procedures has a special symbolic meaning in the generation of the forms of Hindu temples.

Key words: Fractal geometry – Cosmology – Hindu temple architecture – Visual language

The architecture of Hindu temples is characterized by certain distinctive formal features (Fig. 1). The most prevalent is a kind of jaggedness of all surfaces and edges. This jaggedness results from breaking or splitting of forms into subforms. The next feature is the profusion of details and elements on the exterior surface of the temple. Figures of deities, human beings, animals and mythical beings, foliage and miscellaneous decorative elements are packed together densely on the exterior to create a distinctive visual texture on the temple surface. These elements are arranged in horizontal layers, which form another distinctive feature. The layers are of varying widths, and they form horizontal bands in the elevation of the temple. Finally, there is the repetition of certain motifs in the temple form in different scales. The same form is repeated in decreasing size within the overall three-dimensional motif.

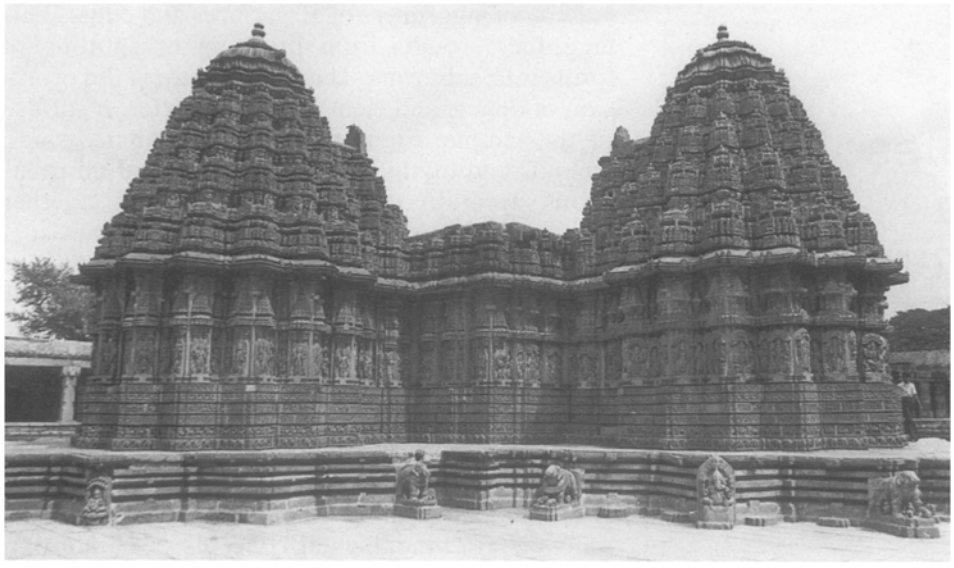
A Hindu temple is a symbolic structure that represents certain fundamental concepts of Hindu philosophy about the nature of cosmos (to be explained later), and the formal characteristics of the temple are an outcome of this symbolic representation. There exists a language of symbolic forms – in which certain meanings have been ascribed to certain geometrical shapes. Ancient Indian texts on ritual art and architecture explain the symbolism of these forms.

Of particular interest in the context of this paper is the convention, according to canons of Indian Architecture, which dictates that all temple architecture must be constructed in a square grid. This condition, the symbolic meaning of which will be explained a little later, results in the peculiar jaggedness of Hindu temple forms and is similar to the jaggedness that exists in the shapes of computer graphics due to presence of a raster grid.

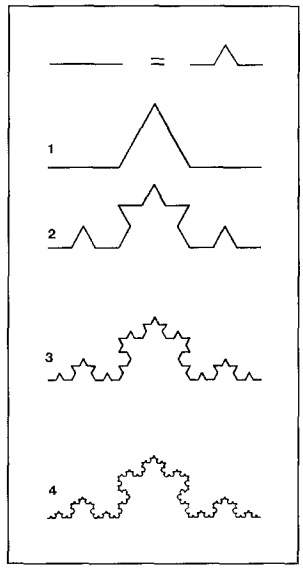
The procedures and methods used in the design and construction of Hindu temples bear a striking resemblance to many of the procedures in computer graphics, including discretization, fractalization, extensive use of recursion and procedures involving self-similar iteration. The instructions for these operations are given in the procedures described in ancient texts on architectural practice (called *Vastu-shastras*); and many of these instructions are in the nature of general programmes from which different temple forms may be generated.

This paper is an attempt to draw attention to some of the similarities between procedures and the resulting forms in computer graphics and Hindu temple architecture and to explain the relationship between the form of the temple and the concepts of Hindu philosophy. The subject of symbolism of

The Visual Computer (1989) 5:243–258



1



2

Fig. 1. Some of the characteristic visual features of Hindu temples: jaggedness of form, profusion of details, horizontal bands, and repetition of motifs; as seen in the Keshava Temple, Somnathpur

Fig. 2. Generation of Koch's curve (with a typical snowflake appearance) through successive application of the same production rule

Hindu temple architecture is vast and requires an understanding not only of Hindu philosophy but also the nature of religious practices, rituals and temple worship in Hinduism. This paper neither claims to be comprehensive nor exhaustive in explaining these concepts and will only describe, in a simplified manner, some of these concepts and how they affect the form of temple architecture.

Temple forms, fractals and self-similarity

Of the various correspondences between computer-generated images and forms in Hindu temples, the most striking is the resemblance of temple forms to images based on fractal geometry. The concept of fractals (Mandelbrot 1977) characterizes objects that exhibit invariance under scaling. A fragment of such an object, on being enlarged, exhibits an appearance and properties that are very similar to the whole. When each part is geometrically similar to the whole, such a shape is called self-similar. Self-similar shapes abound in nature: mountains and trees, clouds and lightning, river deltas and coastlines – all exhibit self-similarity. Although the existence of the phenomena of self-similarity in the natural world has been observed and known for a long time, the process of its mathematical understanding only began with Mandelbrot's work. Apparently disordered and amorphous shapes like clouds and islands were shown to be based on a fractal order involving repetition on a constantly decreasing scale of a single similar difference. It has been proposed that fractal geometry provides a closer mathematical model of many shapes in nature than is possible with conventional geometry (Mandelbrot 1977).

A self-similar shape may be constructed by successive replacement in a gradually decreasing scale of an initial shape 'a' (initiator) by another shape 'b' (generator). The production rule for this may be expressed as $a \rightarrow b$. By iteration of this kind, beginning from very simple shapes one can arrive at shapes that appear to be very complex visually. Koch's curve (Mandelbrot 1982) is a well-known example of this kind (Fig. 2).

Some very fascinating visual images have come out from computer graphics based on fractal geometry (Peitgen et al. 1986). Many of these images evoke the feeling of forms found in nature. They go beyond just being the visual results of a mathematical process with interesting properties, but touch us deeper, almost on a spiritual level, like all objects of pure beauty.

Interestingly, self-similarity is also one of the fun-

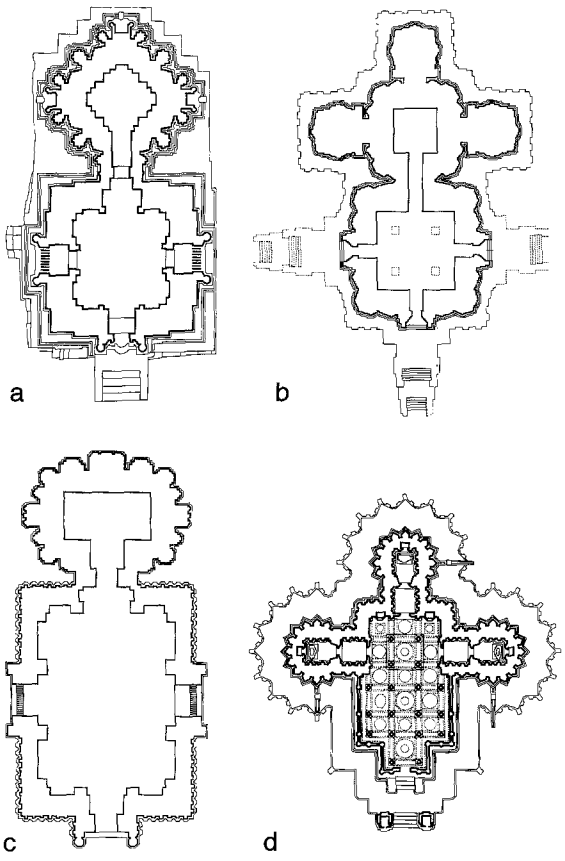


Fig. 3a–d. Plans of some Hindu temples displaying the snowflake curves characteristic of fractal figures. The plans are of: **a** Temple of Raja Rani, Bhuvaneshwar; **b** Sun Temple, Konark; **c** Varahi Temple, Caurasi; and **d** Keshava Temple, Somnathpur; all constructed between 12th & 13 Century, A.D.

damental principles of organization in the architecture of Hindu temples, which are designed and constructed as models of the Cosmos as envisioned in Hindu philosophy. There is a striking similarity between the plans of these temples and some computer-generated fractal shapes (Fig. 3). Countless temples exist all over India (some dating back to the fifth century A.D. and together representing nearly 1500 years of architectural endeavor), which could be viewed as three-dimensional structures based on fractal geometry.

To understand the importance of self-similarity as an organizing principle in Hindu temple architecture and the prevalence of fractals in its form, some understanding of the metaphysical basis of Hindu temple architecture is necessary.

Hindu cosmology

Hindu philosophy views the Cosmos as essentially holonomic (and as a consequence self-similar). Like a hologram, each fragment of the cosmos is believed to be whole in itself and to contain all the information of the whole. This property is expressed in the well-known peace invocation from *Isha Upanishad* (*Upanishads* are ancient texts of Hindu philosophy) given below:

Om
That is Whole
This is Whole
From Wholeness emerges Wholeness
Wholeness subtracted from Wholeness
Wholeness still remains.

Implicit in the notion of holonomy are the properties of homogeneity, isotropy, self-similarity and symmetries of various kinds.

This notion about the nature of cosmos is reiterated in many texts of Hindu philosophy. A verse from *Kathopanishad*, another principal *Upanishad* says, "Whatever is here, that is there; what is there, the same is here." (*Kathopanishad*, 4.10).

The *Pinda-Brahmanda* theory of a school of Hindu philosophy called *Samkhya* proposes the existence of a correspondence between the macrocosm and the microcosm. The entire cosmos can be visualized to be contained in a microcosmic capsule, with the help of the concept of subtle elements called '*tanmatras*'. The whole cosmic principle replicates itself again and again in ever smaller scales. The human being is said to contain within itself the

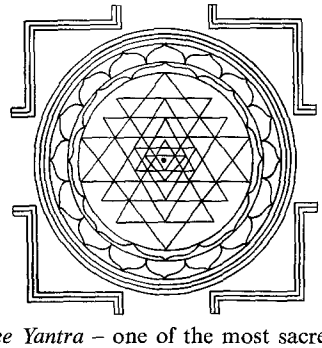


Fig. 4. *Shree Yantra* – one of the most sacred diagrams in Hinduism – depicting the process of cosmic evolution symbolically

entire cosmos. The notions of '*Antaryami Brahma*' – the cosmos within and the invocation '*Aham Brahmasmi*' – I am the cosmos originate from this philosophy.

Another major proposition of Hindu philosophy about the cosmic process is that the cosmos evolves out of the union of two complimentary principles and expands outwards from the centre where the union takes place. This evolution is considered cyclic – the cycles of creation, sustenance and dissolution repeat themselves endlessly. The process is viewed as a continuum. In the vast cosmic activity, certain forms of life are seen to be evolving, while others are simultaneously vanishing and others are static. The expansion can be atomic or infinite. No matter what their magnitude, the expansion and contractions are interconnected and integrated in the general framework supported by the centre.

These propositions about the nature of cosmos were formulated and laid down thousands of years ago, when philosphy and natural sciences were not considered separate disciplines. The ancient texts of Hindu philosophy – the *Vedas*, and the *Upanishads*, contain these propositions, which are said to have been revealed to the sages during their quest for the absolute truth. The same sages who propounded these theories are also attributed with the founding of the basic canons of art and architecture. To maintain harmony, all man-made objects and structures were enjoined to be fashioned with the same measurements and principles with which the cosmos is made, and so the underlying order and symmetries of the cosmos manifest themselves in the designs and representations made by man.

Symbolism of basic geometrical forms

To express these propositions symbolically in diagrammatic form, basic geometrical figures such as point, circle, triangle, square etc. were assigned special symbolic meaning in Indian sacred art to represent the basic energies of the cosmos. These symbolic geometrical figures were then combined in increasingly complex figures to represent particular qualities or forces embodied in some aspect of creation, evolution or dissolution.

In Indian sacred art, the 'point' (*bindu*) is considered as the source of all creation. It represents concentrated energy, the primordial centre. From this centre emanate the various lines, triangles and circles culminating in different shapes. A point can be considered as a circle with no radius. It can also be considered a triangle with no area, a point where the would-be three vertices coincide. All forms are potentially present in the point.

The circle represents the principle that has no beginning, no ending and which is perfectly symmetrical. It indicates the realm of radiations from the one centre. "The Circle is All (Universe)", according to *Vastusutra Upanishad*, an ancient text on the significance of form in sacred art (Boner et al. 1986).

The triangle is the basic linear figure of enclosure. Since space can not be bounded by less than three lines, the triangle is conceived as the first symbolic form to emerge from the chaos preceding creation. The downward pointing triangle is representative of the female principle, while the upward pointing triangle denotes the male principle. The interpenetration of these two triangles represents the concept of fusion of polarities: the male and the female; matter and spirit; the static and the kinetic in a perfect state of unity.

A square denotes the manifest world, the stable linear form representing the earth. It is the fundamental format of the most of the sacred constructions, denoting the terrestrial world that must be transcended.

From these basic forms, many different geometrical diagrams representing the various symmetries and energies of the cosmos are constructed. These diagrams are used as meditative tools or instruments to awaken in oneself these energies. The diagrams are variously called *Mandalas*, *Yantras*, and *Chakras* (Fig. 4).

'*Mandala*' is a Sanskrit word meaning polygon. In ritual diagrams *Mandalas* signify 'Wholeness'. Their preferred shapes are circles and squares. Traditionally, the circular *mandalas* are symbolic of the cosmos in its entirety and the square symbol of the earth and of the man-made world.

'*Yantra*' is also an abstract geometrical design intended as a tool for meditation. The Sanskrit word '*Yantra*' derives from the root '*Yam*' – meaning to sustain, hold or harness. *Yantra* is an instrument, a store-house of energy.

While *mandala* is cosmic, *yantra* relates to a specific aspect of cosmic power and may be the representation of a particular deity, a specific *yantra* containing in itself in a controllable form the uncontrollable form of a deity. Every *yantra* is a sacred enclo-

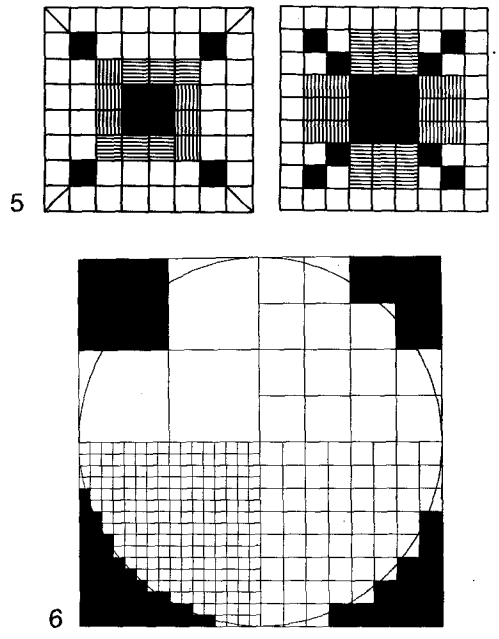


Fig. 5. *Vastupurusha mandalas* of 8×8 (64) and 9×9 (81) squares. The principal deity resides in the central square, with auxiliary deities surrounding it in the outer rings

Fig. 6. Representation of a circle in successively finer square grids and the resulting jaggedness of the edge

sure, a dwelling or a receptacle of a chosen deity. It is a substitute for an anthropomorphic image of a deity and is an abstract translation of the attributes and powers of the deity.

The temple architecture tradition

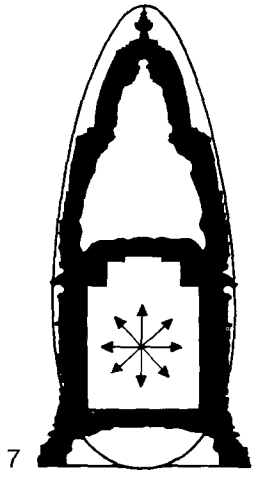
All Hindu temples are built on the scheme of the ritual diagrams: *yantras* and *mandalas*. These architectural yantras can be interpreted as three-dimensional models of the cosmos and the cosmic process. The notion of temple as a model of the cosmos has existed for over 3000 years in texts and for more than 1000 years in actually realized monuments. This notion forms and constitutes the very nature of the temple in many styles throughout India (Kramrisch 1975).

The science of temple architecture is laid down in ancient texts that are called '*Vastu-shastras*', and their scope includes not only architecture, but also sculpture and painting. The *Vastu-shastra* texts are instruction manuals for the practising architect and describe in detail the construction of the temple from the selection of the site, measurements and proportions and structural process to the establishment and consecration of the presiding deity. The texts generally consist of verbal instructions and formulae intended for the architect who is already well-versed in the basic skills of architecture and can work from these formulae. The many different types of temples (*Samrangana-sutradhara* – an eleventh-century treatise on architecture describes 64 different kinds of temples) and the way to construct them is described in general programmes. By making certain initial decisions and following the given rules of proportion, growth and measurements, all the specific details and dimensions of a temple to actually be constructed can be worked out.

The system of measurement followed by the *Vastu-shastras*, called the '*Tala*' system, does not depend on absolute dimensions, but defines all dimensions as sets of relationships of proportions of component parts with respect to the whole. This system has the advantage that it is possible to work out the proportion of the parts irrespective of the overall size. The rules of proportion could be used for gigantic figures to be cut in rock temples, as well as for small figurines to be carved in ivory. The existence of such a general programme of proportional relationships, independent of absolute size, enables the same procedures to be repeated in gradually dimishing sizes in correspondingly smaller grids – theoretically up to infinity. This feature was of great importance, considering the many self-similar procedures that had to be carried out in determining the forms of various parts of the temple.

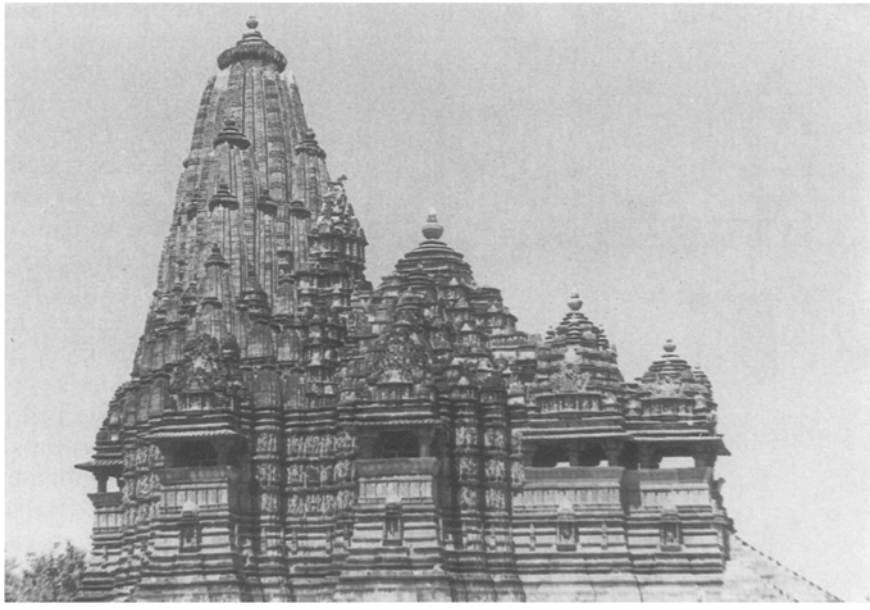
The cosmology of the temple plan

According to *Vastu-shastra* tradition, the ground plan of every Hindu temple must conform to a *mandala* called the '*Vastu-purusha Mandala*'. Great importance is attached to the establishment of the *Vastu-purusha Mandala*, because it functions as a geometrical diagram of the essential structure of the universe, an imprint of the ordered cosmos. The *Vastu-purusha Mandala* is not an exact blueprint of the temple, but a 'forecast', a marking of the potential within which a wide range of possibilities are implied. The *mandala* is an ideogram while

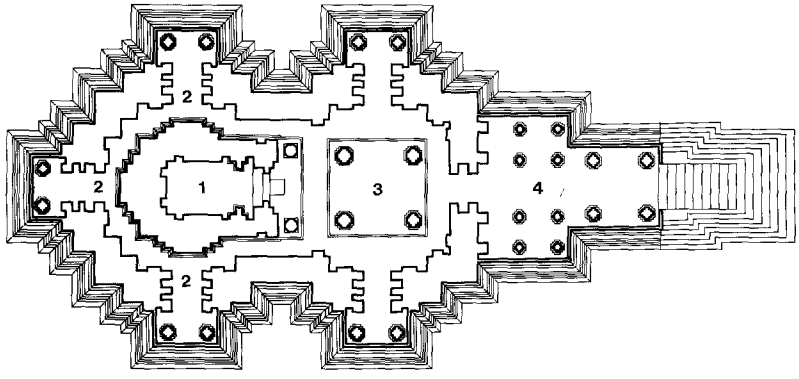


7

Fig. 7. The temple as cosmos. The overall shape is that of *Brahmanda* (the Cosmic egg). Evolution starts from the centre and expands outwards in all directions



8a



8b

Fig. 8. The elevation and plan of Kandariya Mahadeva temple at Khajuraho (eleventh century A.D.) to explain the component parts of a fully evolved Hindu temple. The parts are (as marked in the plan):
1. *Garbha-griha* (sanctum);
2. Ambulatory passage;
3. *Mandapa* (hall); and
4. *Ardha-mandapa* (entrance porch)

the temple is a material manifestation of the concepts it embodies (Fig. 5).

According to the conventions of *Vastu-shastra*, all architectural constructions should follow the square and the square grid, as the square symbolizes the manifest world. This is in accordance with the symbolism that links the Earth and the Earth field with the square shape: "What is Earth should be *Vastu* (architecture), what is *Vastu* is the Earth" (*Shilpa-sastram*, 2.15).

However, as the cosmos is represented by the circle symbolically, the process of making an architectural model of the cosmos involves the representation of a circle in a square grid in two-dimensional construction and of an ellipsoid (the cosmic egg) in a cubical grid in three-dimensional construction. A process of discretization of all curved forms is necessiated by this need to represent them in a square grid, which results in the typical jaggedness of the temple plan (Fig. 6).

According to *Vastu-shastra* texts, a series of 32 types of *Vastu-mandalas* is said to exist, progressing from a plan of one square to one (1×1) to one with 1024 (32×32) square subdivisions, i.e. having a side length of 32 units. The two most commonly used *Vastu-purusha Mandalas* are those having 64 (8×8) and 81 (9×9) squares. The increasing number of subdivisions are required to represent the gradually increasing complexity and details of an evolving cosmos. The simple, smaller temples based on the smaller *mandalas* represent the early stages of evolution, while the largest temple contains all the component parts and complexity of a fully evolved cosmos.

Parts of the Hindu temple

The image of the presiding deity in the temple forms the conceptual centre of the temple as cosmos, from which the evolution of the cosmic process begins – expanding outwards in all directions until a fully realized cosmos is manifested in visible form in the intricate details of the exterior of the temple. The central, inner sanctum housing the main deity is known as '*garbha-griha*' (literally meaning 'womb-chamber') and is dark, plain and without the complex details found in other parts of the temple (Fig. 7).

The essential elements of the plan of a Hindu temple consist of an *ardha-mandapa* (entrance porch), *mandapa* (hall), *antarala* (vestibule) and *garbha-griha* (sanctum). In the larger temples, however, balconied windows are added to the *mandapa*, turning it into a *maha-mandapa* (great hall). The larger temples also introduce an inner ambulatory around the sanctum (Fig. 8).

The temple in its elevation is considered an integral whole of three basic parts: the *pitha* (base), the *mandovara* (wall), and the *shikhara* (spire). The *pitha* in its most developed form is composed of seven consecutive mouldings bearing repetitions of different prescribed motifs. The *mandovara* supported on the *pitha* is resolved into three major components: *Vedibandha* (podium), *jangha* (the wall proper in the central zone) and the *varandika* (eave cornice).

Above the central zone of the wall proper rises the roof consisting of a series of graded peaks that resemble a mountain range to which a Hindu temple is frequently compared. These peaks, arranged along the axial line, arise and fall alternately while maintaining the overall upward ascent, and culminate in the tallest spire (*shikhara*), which is raised directly over the sanctum. The developed, more evolved temples are characterized by an intricate arrangement of subsidiary *shikharas* of various sizes attached to the main *shikhara.*

Fractal elements in Hindu temples

In depicting an evolving cosmos of growing complexity, which is self-replicating, self-generating, self-similar and dynamic, several geometrical construction procedures are followed in the architecture of Hindu temples. The growth accompanying evolution can not be expressed merely by scaling; there is also a growth in the complexity of the evolving shapes. The procedures used are recursive and generate visually complex shapes from simple initial shapes through successive application of production rules that are similar to the rules for generating fractals. Many different rules may be followed to generate different parts of the temple – the total temple form results from a complex interweaving and combination of these different three-dimensional shapes in an integrated whole.

Some major procedures to generate complex shapes and patterns, which can be identified are:

1. Fractalization
2. Self-similar iteration in a decreasing scale
3. Repetition, superimposition and juxtaposition

Fractalization

Many different techniques of fractalization to achieve greater visual complexity to express the idea of multiplying and growth are found in existing temples. In the columns of rock temples dating back to second century A.D. (Fig. 8), one can find a square section being split into an 8-, 16- and 32-sided polygon in successive sections along the length of the column. The production rule for this can be expressed as $P(n) \rightarrow P(2n)$, where P is a regular polygon of 'n' number of sides. The use of this technique to achieve transition of the section of the pillars from square to a circular section is commonly found in Hindu temples (Fig. 9).

Splitting or breaking up a motif and repeating it horizontally, vertically or radially around the original motif is another technique used to increase the complexity of the original motif. Such patterns are commonly found in ceiling part of the temples. The jaggedness of the sides created by this operation is followed throughout the elevation in three-dimensional motifs, giving the overall form a vibrant, dynamic appearance (Fig. 10.)

In the prescribed series of plans of *garbha-grihas* of progressively larger temples, the plain square shape of the *garbha-griha* acquires complexity as it grows in size by fractalization created by increasing the number number of projections both on the interior and the exterior walls (Figs. 11, 12), giving it its typically jagged appearance. Plans of eight different types of *mandapas* show the same pattern

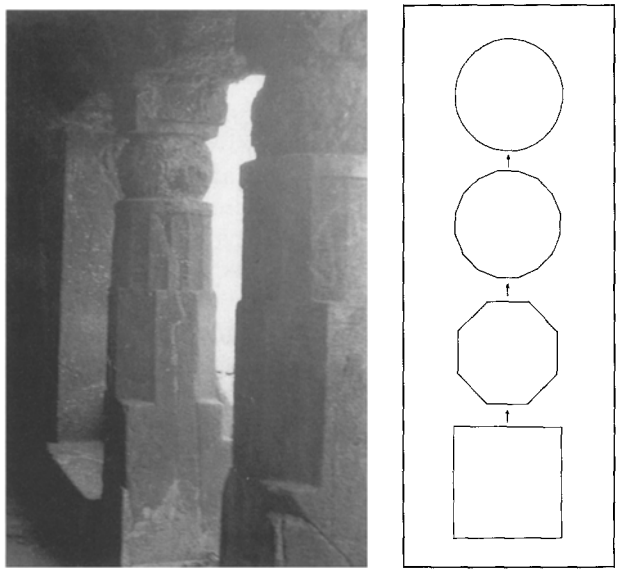
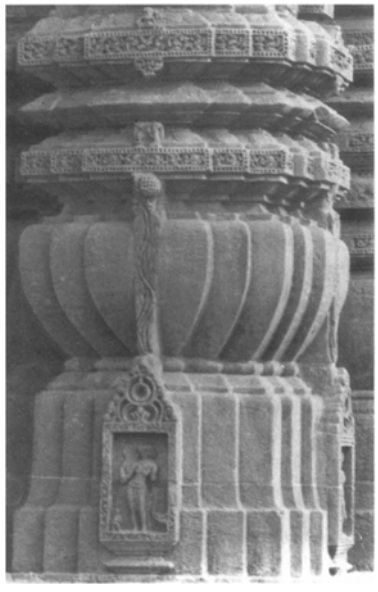


Fig. 9. The transition from square to circle in the column of rock-cut cave temple at Karla (second century A.D.), achieved by progressively doubling the number of sides of the base square

of growing complexity with the increase in size (Fig. 13). The projections or offsets in the base plan of *shikharas* proliferate in number from 3 to 9 (Fig. 14) in successive generations. Even subsidiary structures like water reservoirs (*kundas*) near the temple for washing and ritual purifying are described as a series of structures of growing complexity, with the plain square plan of the simplest type being fractalized in multiple-sided plan by successive replacement of the plain sides with sides having an increasing number of projections (Fig. 15.)

The multipointed star-shaped ground plans of many types of temples are created by a recursive procedure involving rotation and the superimposition of the original polygon on itself. Such roughening or fractalizing procedures are described for many different types of polygons (Fig. 16).

There is a marked preference for jagged, fractalized forms in Hindu temple architecture. Sudden, discrete transitions are preferred to the continuous



10

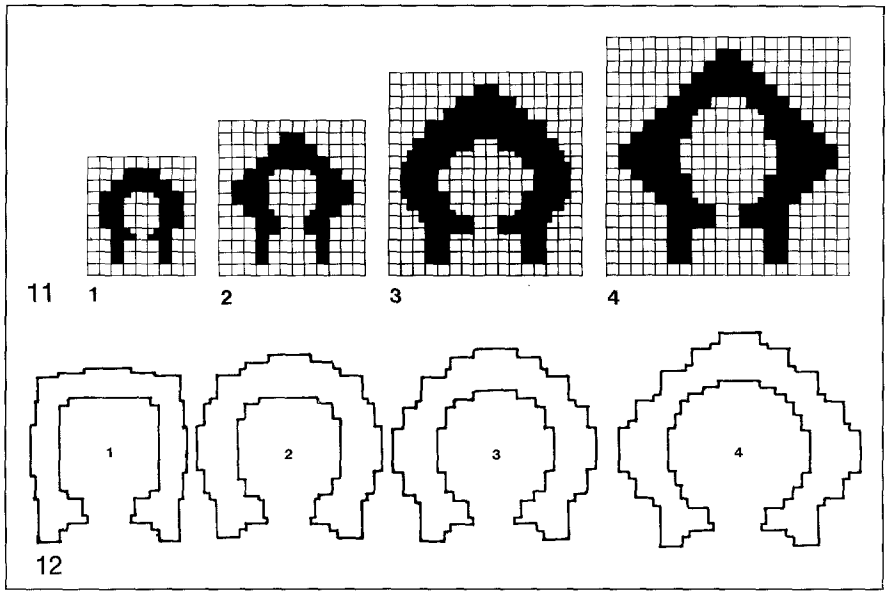
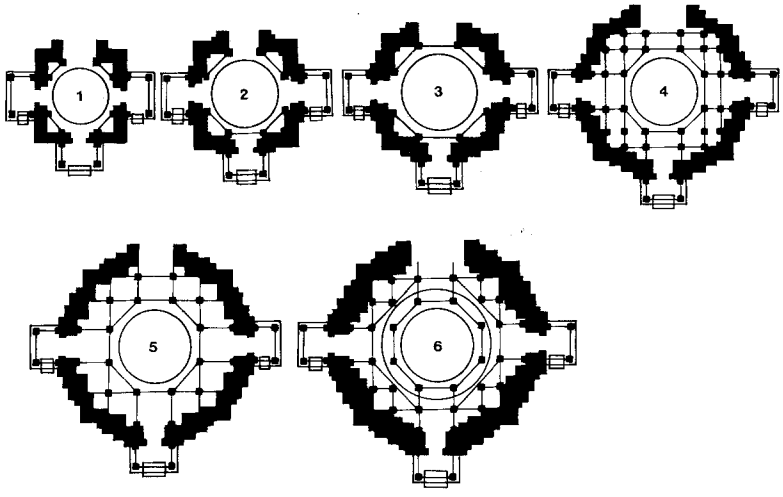
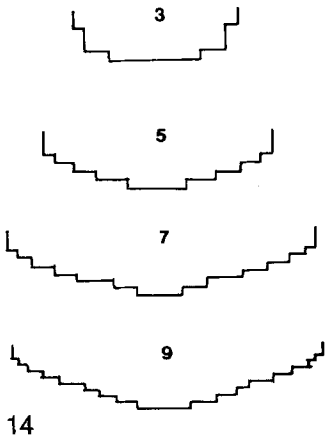


Fig. 10. Fractalization in a three-dimensional motif, achieved by splitting/breaking of the main form in all directions

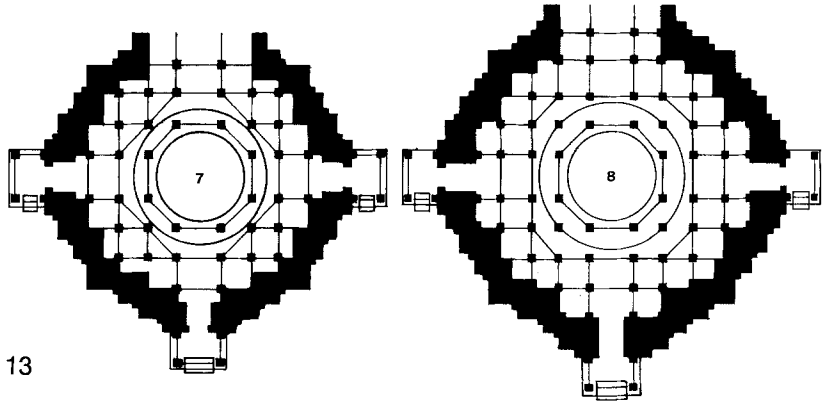
Fig. 11. Plans of *Garbha-grihas* of various types: 1. *Trianga*; 2. *Panchanga*; 3. *Saptanga*; 4. *Navanga*, showing the growing complexity with increase in size

Fig. 12. Growing complexity of components on both the interior and exterior wall of the various types of *garbha-grihas*. On the inner wall the plans are with the components called: *Bhadra* (2), *Subhadra* (3), and *Pratibhadra* (4), while on the exterior walls with *Arya* (1), *Hastangula* (2), *Bhagava* (3), and *Samadala* (4)





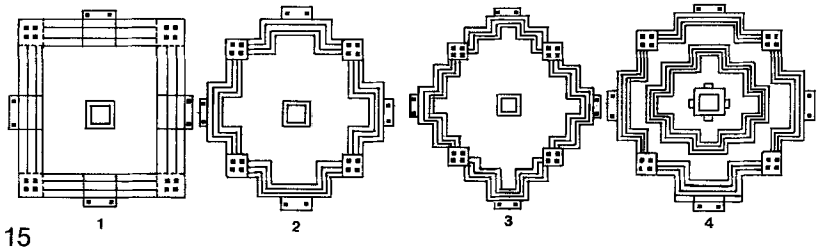
14



13

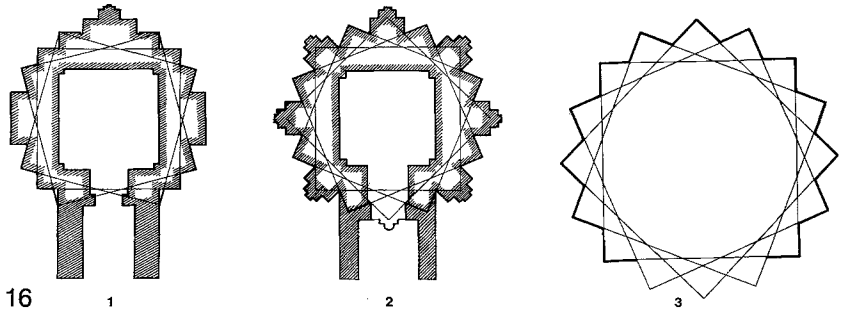
Fig. 13. Plans of 8 types of *Mandapas* as described in *Shilpa* texts: 1. *Vardhaman*; 2. *Swastika*; 3. *Garuda*; 4. *Suranandan*; 5. *Sarvatobhadra*; 6. *Kailash*; 7. *Indranila*; 8. *Ratnasambhava*

Fig. 14. Increasing number of self-similar projections or offsets in various types of base-plans of *Shikharas* as described in *Shilpa* texts: 1. *Trinasaka* (3 offsets); 2. *Panchanasaka* (5); 3. *Saptanasaka* (7); and 4. *Navanasaka* (9)



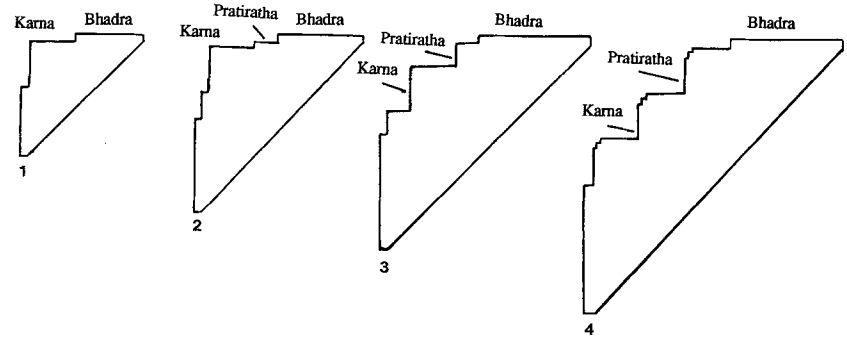
15

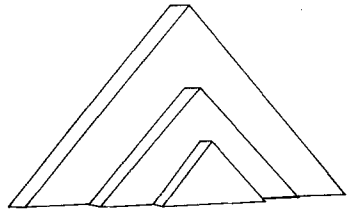
Fig. 15. Plans of *Kundas* (water reservoirs) of various types: 1. *Bhadra*; 2. *Subhadra*; 3. *Nanda*; and 4. *Paridh*

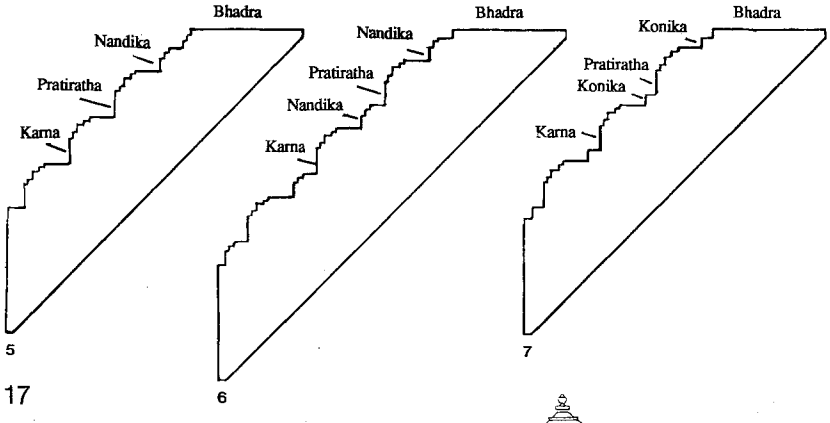


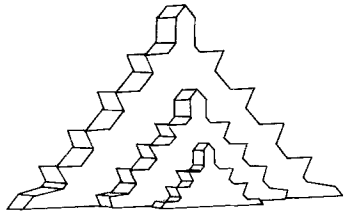
16

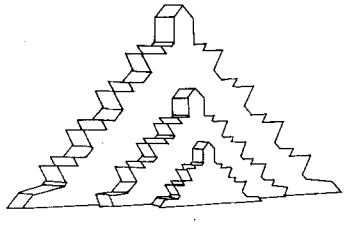
Fig. 16. Generation of star-shaped plans of some temples by rotation and superimposition of a square shape: 1. *Samadala Prasada*; 2. *Ashatansha Prasada*; 3. Basic construction for generating the star of the plan of the Keshava temple shown in Fig. 3d

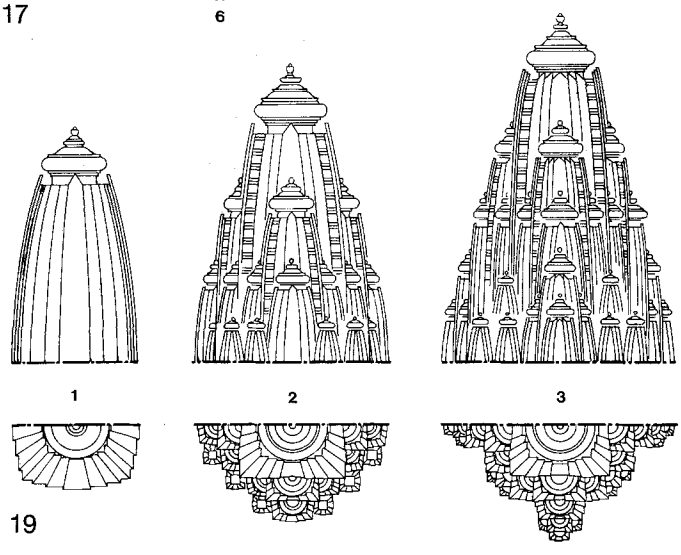












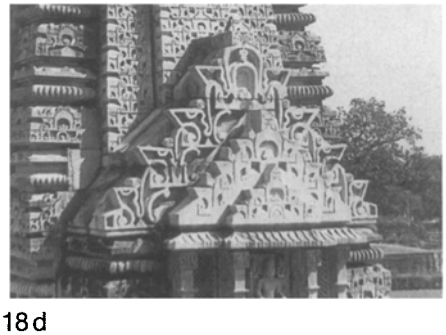


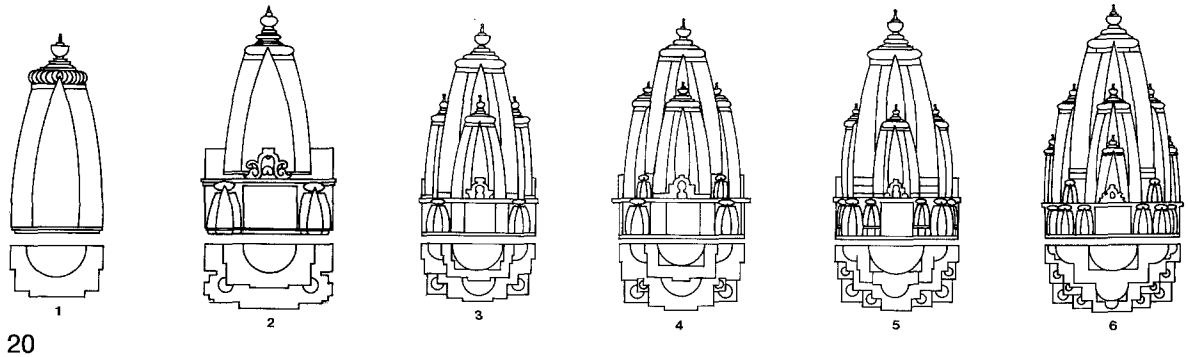
Fig. 17. Details of wall plans showing increased number of components obtained by self-similar iteration of the side. The types are: 1. *Dvi-anga* with two proliferations; 2, 3, 4. *Tri-anga* with three; 5. *Chaturanga* with four; and 6, 7. *Panchanga* with five

Fig. 18. Steps in the gradual evolution of a typical motif by self-similar iteration in three-dimension of a triangular shape

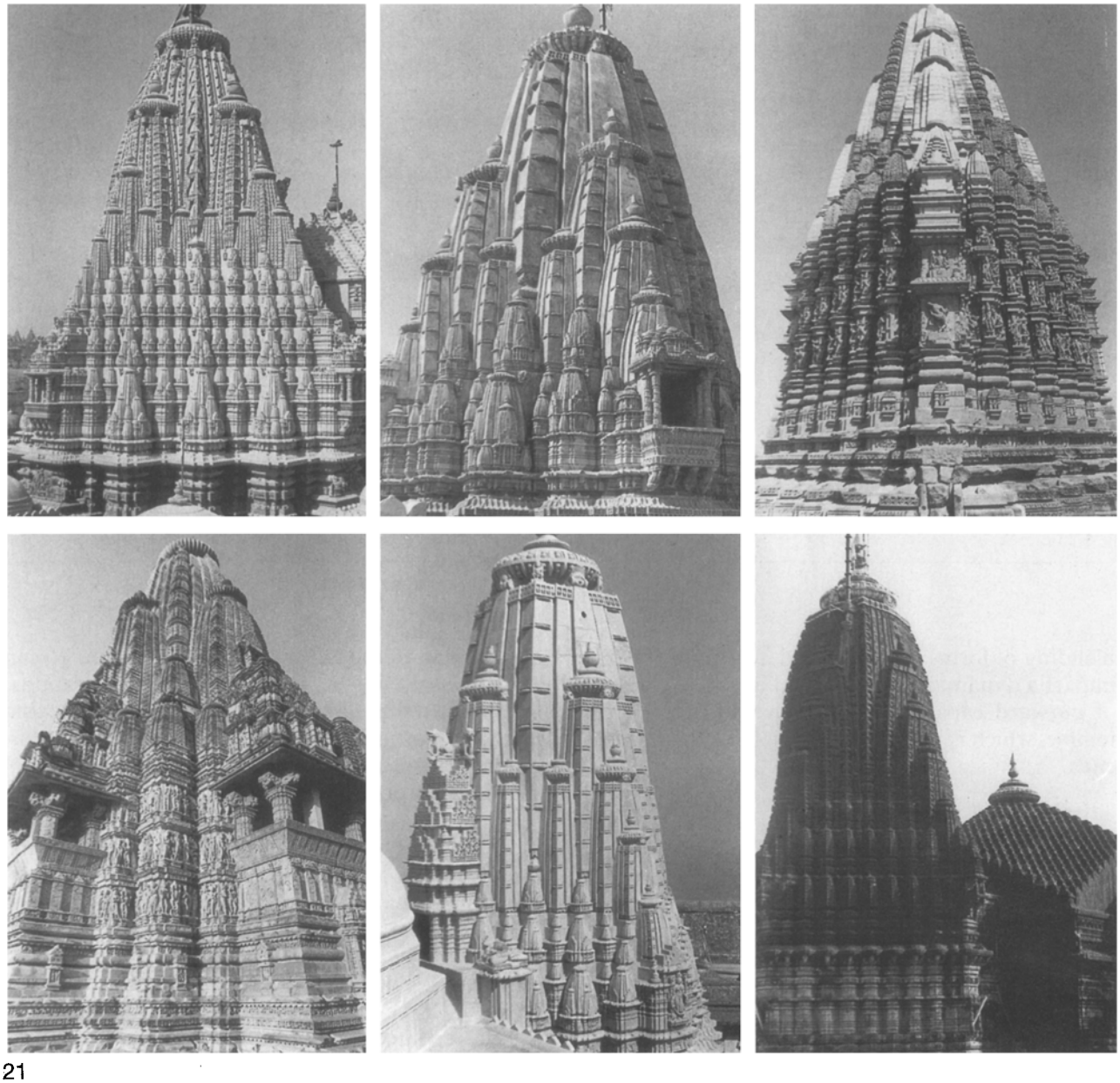
Fig. 19. Progression from simple to complex *shikharas* at Khajuraho: 1. Adinatha Temple, 950 A.D.; 2. Parshwanatha Temple, 970 A.D.; and 3. Kandariya Mahadeva Temple, eleventh century A.D.

Fig. 20. *Shikharas* of various types of increasing number of self-similar spires: 1. Basic spire called '*Srivatsa*'; 2. *Keshari* (5 *shringas*); 3. *Sarvatobhadra* (9 *shringas*); 4. *Nandan* (13 *shringas*); 5. *Nandashal* (17 *shringas*) and 6. *Mandara* (21 *shringas*)

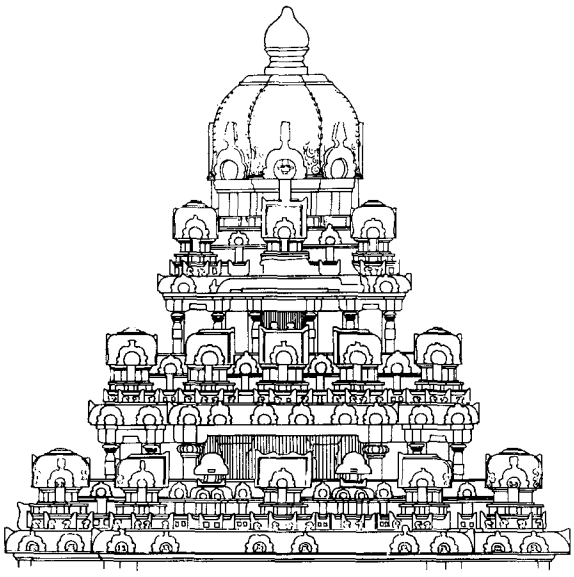
Fig. 21. Examples of *shikharas* of various Nagara style temples in India (from tenth to fourteenth century A.D.), showing varieties of forms and the extent of self-similar iteration



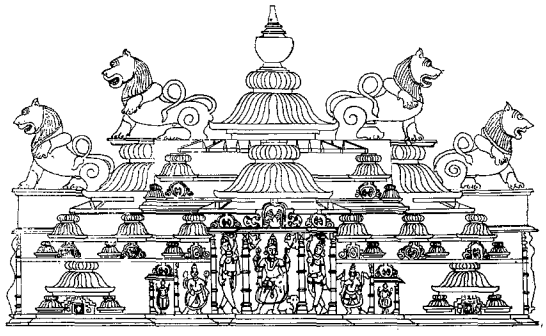
20

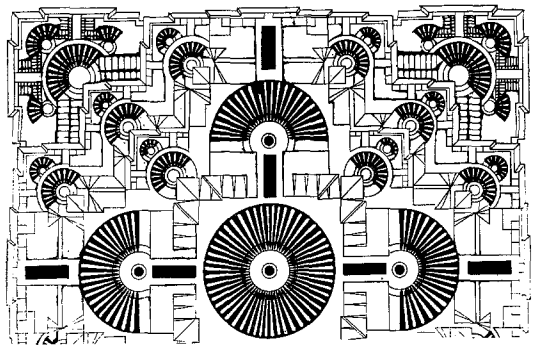


21

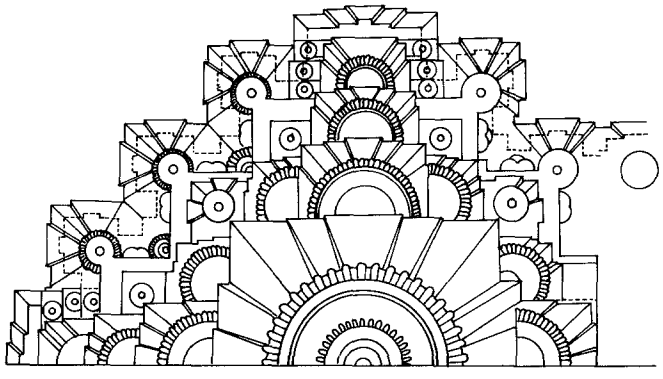


22





23



24

Fig. 22. *Shikhara* of Mahabalipuram Dharmaraja ratha, showing the pattern of iteration in Dravida-style temples

Fig. 23. Top view of the *Samvarna* (canopy) over *Mandapa*

Fig. 24. Half-plan of the *Samvarna* of Nilakantha Mahadeva temple in Sunak, Gujarat (eleventh century A.D.)

blending of forms. These jagged, fractalized shapes impart a dynamic, vibrant visual quality suggestive of outward expansion to the overall form of the temple, which is perhaps the reason for their preference.

Self-similar iteration in a decreasing scale

A recursive procedure involving self-similar iteration in a gradually diminishing scale is frequently used to generate the forms of many parts of the temple. The wall plan of the Maru-Gurjara style of temple gradually achieves complexity through self-similar iteration. In its simplest form, it can be *dvi-anga*, possessing only two proliferations: *bhadra*, also called *ratha*, (central offset) and *karna* or *kona* (corner). In the *tri-anga* temple, an additional member called *pratiratha* (companion of *ratha*) is inserted between the *bhadra* and *karna*. In the *chaturanga* plan, a *nandika* (half the size of *pratiratha*) is added between the *bhadra* and the *pratiratha*. In a *panchanga* plan, an additional *nandika* or its half – the *konika* is inserted between the *karna* and the *pratiratha* (Fig. 17).

A commonly seen motif on the exterior walls of temples is generated by fractal operation on a triangle in three-dimension, and the resulting shape is furhter superimposed with another decorative pattern (Fig. 18). The most complex and visually

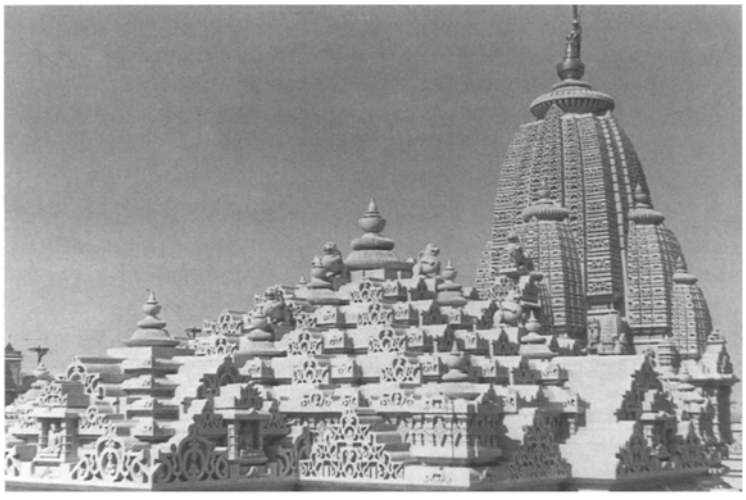


Fig. 25. *Shikhara* and *Samvarna* of Jain Temple at Shatrunjaya, Palitana

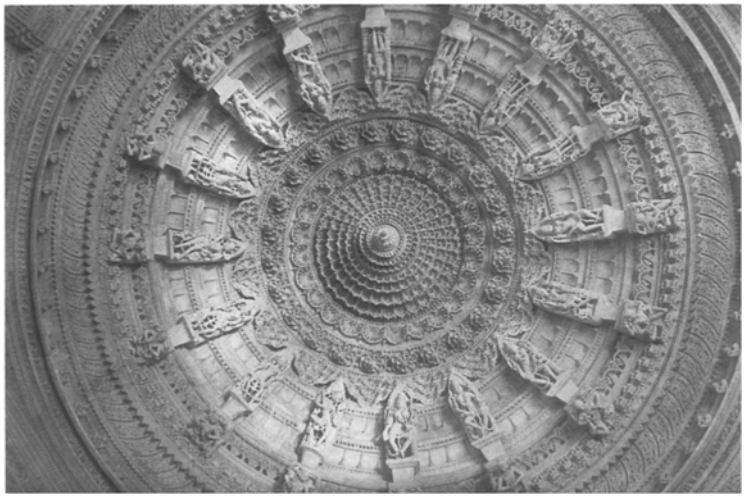


Fig. 26. Sculptured ceiling panel from Jain Temple, Abu, depicting a *mandala* symbolizing the evolving cosmos, consisting of many self-similar worlds expanding outwards from the centre

interesting examples of self-similar iteration in three dimension are found in the *shikhara* (spire) part of the temple in both the two major styles of Hindu temples: Dravida and Nagara.

In the Nagara *shikhara*, the application of a recursive procedure applied in three dimension makes the high tower of the *shikhara* throw forth diminutive multiples of its own shape in high relief, each one and all of them subordinated to the bulk of the total *shikhara* (Fig. 19). The part *shikharas*, called chest-*shikharas* or *uro-shringas*, each being half a *shikhara* and a submultiple of the total shape, cling to the 'chest' of the '*Purusha*' – which this part of the temple is supposed to represent (the whole temple representing the cosmos in the form of human body – the *Purusha*). These sub-*shikharas*, ranging in height to a given part of the total *shikhara* and graded down to miniature *shikharas*, may be grouped in horizontal series at the springing of the curve of the total *shikhara*. Each miniature *shikhara* is a model of the shape of the total *shikhara* – complete with its component parts (Figs. 20, 21).

A typical instruction for recursive construction, as given in 'Kshirarnava', a text on temple architecture, goes like this:

> The layer of *Prahara* (projection) will be above the *chadya* (eave of the roof) – this is to be repeated again and again on the spire over the spire. A fraction of *prahara* is to be constructed and again the spires are to be constructed. Each of the upper spires will be sprouted out with a measurement equal to half the size of the lower spire (Kshirarnava, 7.113).

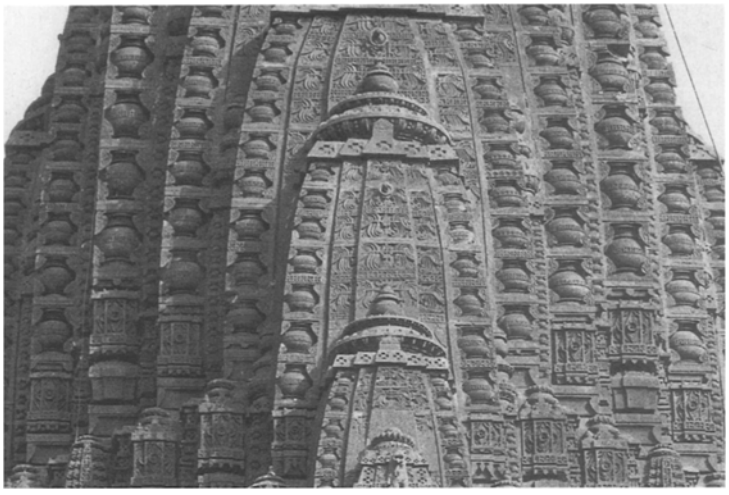


Fig. 27. Details from the *shikhara* of Triambakeshwara Temple, Nasik, showing a repetition of the same motif in successively diminishing layers

Fig. 28. Repetition, juxtaposition and superimposition of many different motifs in the exterior wall of a temple at Khajuraho

In south Indian temple architecture (Dravida style), the superstructure of the *vimana* (temple) or its several storeys is set with small temple shapes, similar to the original shape. The smaller shapes are aligned in a definite pattern at each horizontal level, the repetition of these shapes at each band forming a kind of garland at each level (Fig. 22).
The form of covering or canopy on the top of the *mandapa*, called '*Samvarna*' is also derived from a recursive process, starting from the centre and progressing outwards (Figs. 23–25). A series of 25 types of *samvarnas* are described in the *Vastu* texts – with the number of circular domes called '*ghantas*' increasing from 5 in *Pushpita* to 101 in the type called *Meru Kulodbhava*. The upper part of the ceiling of the *mandapa* called *vitana* usually portrays an expanding *mandala* depicting self-similar worlds arranged concentrically (Fig. 26.)

Repetition, superimposition and juxtaposition

The repetition of identical shapes, either in the vertical or in the horizontal, or vertically as well as horizontally, is another frequently used procedure to add visual complexity to the temple form. The rules of repetition and diminution act conjointly and almost ad infinitum (Fig. 27).
Stella Kramrisch describes the significance of these processes in her *The Temple as Purusha*:

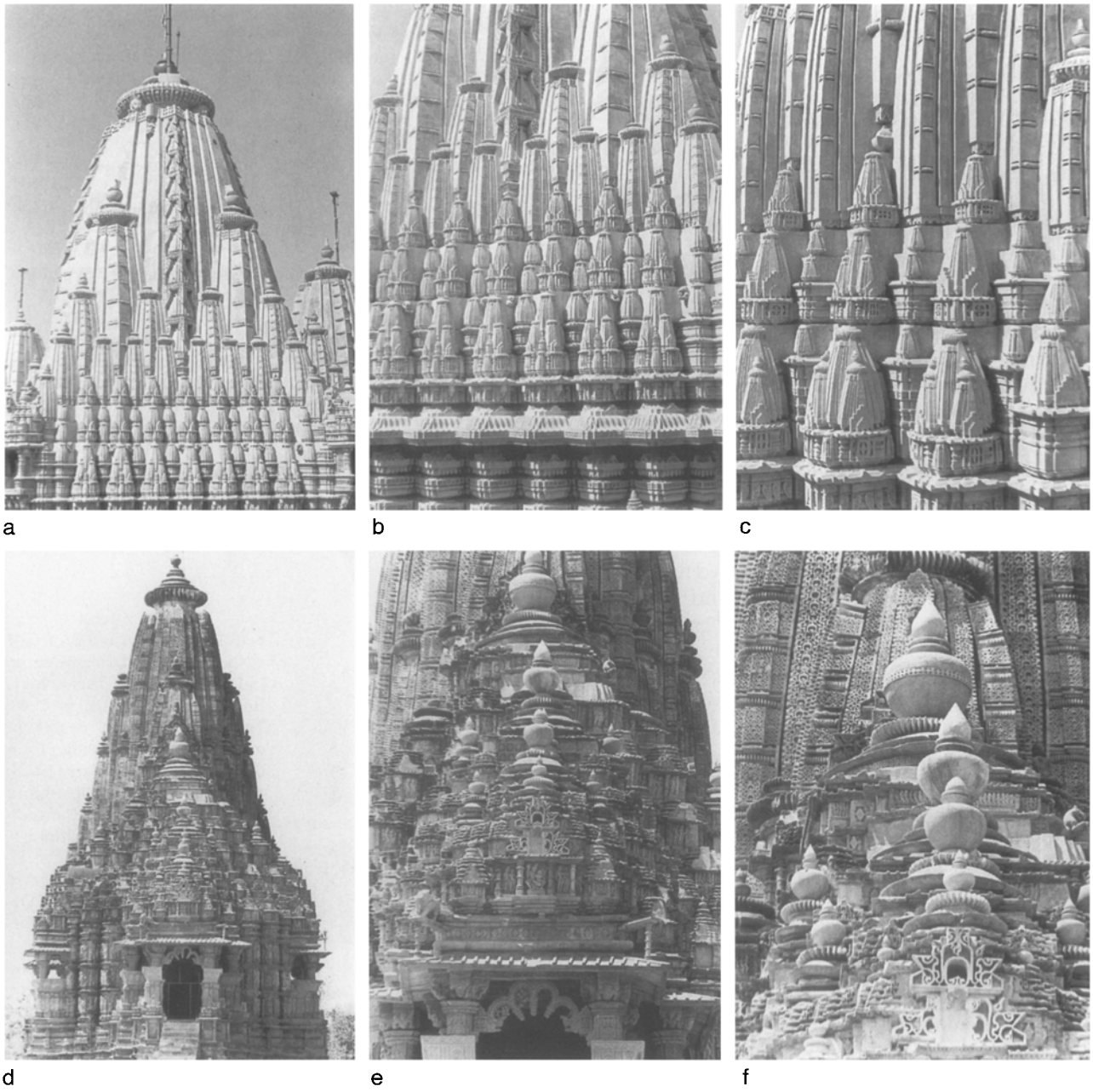


Fig. 29. Progressive enlargements of parts from *shikharas* of Jain temple at Shatrunjaya, and Kandariya Mahadeva temple at Khajuraho, revealing existence of self-similar structures in smaller sizes

While the several, graded diminutions of the size of a given shape are of an intellectual nature, by expressing a hierarchy or valuation in measurable form, the repetition of the diminutive shapes of same size springs from more vital sources in the creative process, stemming from a will to assert itself again and again in measurable intervals by means of a chosen shape and its meaning. The measurable, quantitative nature of rhythm stipulates direction while implyinng variation of intensity, like those of ebb and tide, where one is not without the other and each anticipates the next.

In addition to repetition, different motifs are superimposed in three dimension upon each other; motifs are inscribed within different kinds of motifs and several different kinds of themes and motifs are condensed and juxtaposed together into one complex new entity (Fig. 28). Together, all these operations create the total temple form – teeming with complex detail, vibrant, dynamic and self-sim-

ilar (Fig. 29) – like the cosmos it is supposed to represent.

Concluding remarks

The use of recursive procedures involving self-similar iteration and fractalization in the construction of Hindu temples according to ancient architectural traditions has given rise to a very distinct architectural style. The form of this genre of architecture results from an attempt to express certain concepts of Hindu philosophy about the cosmos, using a symbolic vocabulary of forms, as well as construction procedures that also have symbolic significance. Apart from being very interesting examples of the use of fractal geometry in man-made objects, they are also significant in the manner fractal geometry is used to convey specific meanings through the resultant form.

Fractal geometry puts forward the notion of fractal dimension, lying between the conventional one, two or three dimensions. No one who has experienced the majesty of Hindu temples can deny that they manage to express a spiritual quality, perhaps giving to the viewer a glimpse of the spiritual dimensions that may lie beyond three dimensions of the physical world.

New applications for fractal geometry are constantly being found. Mandelbrot's discovery has been heralded as 'the most exciting development since the discovery of quantum mechanics 60 years ago; and will again revolutionize our scientific view of the universe' (Eilenberger G 1986).

It is not often that one can find concrete applications of a new development by going back a thousand years in time. The many Hindu temples all over India provide just this kind of rare opportunity and invite deeper investigation and study of their forms by all those interested in fractal geometry and its applications.

References

Bhattacharya T (1963) The canons of Indian art or a study on Vastu-Vidya. K.L. Mukhopadyay, Calcutta

Boner A, Sarma S, Baumer B (1986) Vastusutra Upanisad. Motilal Banarasidass, Delhi

Burgess J, Cousens H (1975) The architectural antiquities of Northern Gujarat. Bharatiya Publ, Varanasi (reprint)

Chandra P (1975) Studies in Indian temple architecture. American Institute of Indian Studies, New Delhi

Eilenberger G (1986) In: Peitgen HO, Richter PH (eds) The beauty of fractals. Springer, Tokyo Berlin Heidelberg New York, p 175

Khanna M (1979) Yantra. Thames & Hudson, London

Kramrisch S (1976) The Hindu temple, vol I, II. Motilal Banarasidass, Delhi

Mandelbrot BB (1977) Fractals: form, chance and dimension. WH Freeman & Co, San Fransisco

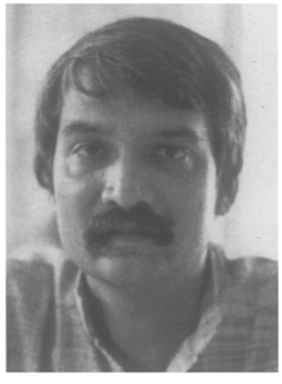
Mandelbrot BB (1983) The fractal geometry of nature. WH Freeman & Co, New York

Meister MW (ed) (1983) Encyclopaedia of Indian temple architecture. American Institute of Indian Studies, New Delhi

Peitgen HO, Richter PH (1986) The beauty of fractals. Springer, Tokyo Berlin Heidelberg New York

Shukla LK (1972) A study of Hindu art and architecture. Chowkhamba Publ, Varanasi

Sompura PO (ed) (1967) Kshirarnava. BP Sompura & Bros, Ahmedabad



KIRTI TRIVEDI is a professor at the Industrial Design Centre, Indian Institute of Technology, Bombay, India. Born in 1948, Trivedi obtained a degree in mechanical engineering from the University of Indore (1970); and a postgraduate diploma in industrial design from the Indian Institute of Technology, Bombay (1972). Later he studied at the Royal College of Art, London, for his Master of Design degree in Industrial Design.

In 1981, he worked in several design offices and design schools in Japan as a UNESCO Fellow. He has been teaching courses in Industrial Design, Graphic Design, Design Methods and Design History at IDC since 1976 and is currently engaged in a project documenting the design traditions of India.

He is the editor of '*Abhikalpa*': *The Journal of Industrial Design Centre* and *IDC/NEWS* – the quarterly newsletter of the Industrial Design Centre, IIT, Bombay. He has edited and published the proceedings of a Seminar on Indian Symbology and a portfolio of contemporary Indian calligraphy. Trivedi's articles and design works have been published in numerous design journals – both in India and abroad.