

# Fractal Geometry in Water Conservation Structures: Step Wells and Tanks in India

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## Abstract

The scientific and philosophical concepts have been transferred from one generation to another through architectural forms and designs since ancient time. Fractal geometry is one such concept which was applied in different forms of architecture, like temples, palaces, town planning and even street designing. The geometric principles used for construction of temples, bridges, water bodies, *stupās*, and their design in plan and elevation are some of architectural and technological marvels achieved in past. This paper describes the application of fractal geometry used in the architecture of artificial water conservation structures in India. The cultural heritage of such structures from the vedic to medieval period has been explored. It focuses on the salient features of step wells and water tanks (*kunda*) as engineering structures and distinguishes between them.

**Key words:** Fractal geometry, *Kunda* (water tanks), Self-similarity, Step well.

## 1 Introduction

The *Chāndogyopaniṣad* (7.10.1) describes the importance of water as: “it is the water which pervades everything, big or small, the earth, the atmosphere, the heaven, the mountains, gods, men, animals, birds, grass, plants, worms, insects, ants. All these are water indeed.” The sages like Vishwamitra and Kashyap had contributed to the methods of construction of water structure as mentioned in ancient scripture (Jain-Neubauer, 1981). Varahamihira’s *Brahatsaṃhitā* (550 CE) presented a modest technique of obtaining potable water from contaminated source. Similarly, Parmāra King Bhoj’s ‘*Samarāṅgansūtradhāra*’ (1000–1050 CE) and Shri Bhuvan Dev’s *Aparājitprchā* (1175–1250 CE) provide the details of clas-

sification and methods of construction of step wells, wells and tanks. *Samarāṅgansūtradhāra* describes three characteristics of step well namely its utility, sustainability and beautification. In ancient India, several engineering structures for harvesting water were designed and developed by the *sthāpatis* (architects and engineers) by identifying sustainable water sources. The step wells were recharged by providing tanks on the upstream. These water storage systems indicate that the *sthāpatis* responsible for the construction of step wells had the knowledge of the geology of the soil as well as the structure and techniques of construction.

Indian mathematicians skillfully used the knowledge of geometry and progression in other disciplines. They observed that mountains, trees, ground covers, water channels and even the living beings follow the principles of self-similarity, iteration and repetition. They followed

these principles in their creations like temples, forts, step wells and water tanks.

### 1.1 Fractal Geometry

The term ‘fractal’ actually originates from the Latin word ‘fractus’ which means ‘broken’. Fractal means, the recursive geometrical arrangements, bearing self-similarity on different scales. Benoit Mandelbrot came up with the name ‘fractal’ in 1975 CE, using the Latin origin ‘fractus’ (fractured, or fragmented). According to the Fractal Foundation – “A fractal is a never ending or infinite pattern”. Fractals are infinitely complex patterns that are self-similar resulting due to iterations across different scales. They are created by repeating a modest process repetitively in an ongoing feedback loop. Fractal designs are enormously acquainted, since nature is full of fractals, e.g. trees, rivers, coastlines, mountains, clouds, seashells, hurricanes, leaves of several trees etc.

Figure 1 shows the gradual transformation of the form of geometry. Figure 1a shows the stage ahead of iteration 2 in Figure 1c. Similarly, Figure 1b shows the transformation from line to branches same as iteration 0 to iteration 1 in Figure 1d. The symmetry with respect to center and line is a basis for further deviation in fractalization of the geometry. Fractal geometry in architecture acts as a mode of expression to reveal the beauty of the complexity. It gives wings to the ideas of an architect and reflects the process of energy flow of the universe through structures and monuments. Hindu temples are one of the best examples of buildings with the fractal phenomenon, which were constructed in the past, long before the concept of Fractal geometry had evolved. The paper tries to study the basic procedures of fractalization, self-similarity in diminishing scale, and repetition and superimposition of shapes to generate complex shapes and patterns with respect to various step wells and *kundas* found in India.

## 2 Fractal theory and Hindu cosmology

The knowledge in ancient times was preserved in the form of mythology and rituals. The Vedic philosophy focuses on life and the universe existed in the form of fractals where there is no origin and no end, in other words singularity in mathematical form (Kiani and Amiriparyan 2016). Scaling up and down of any geometrical shape cre-

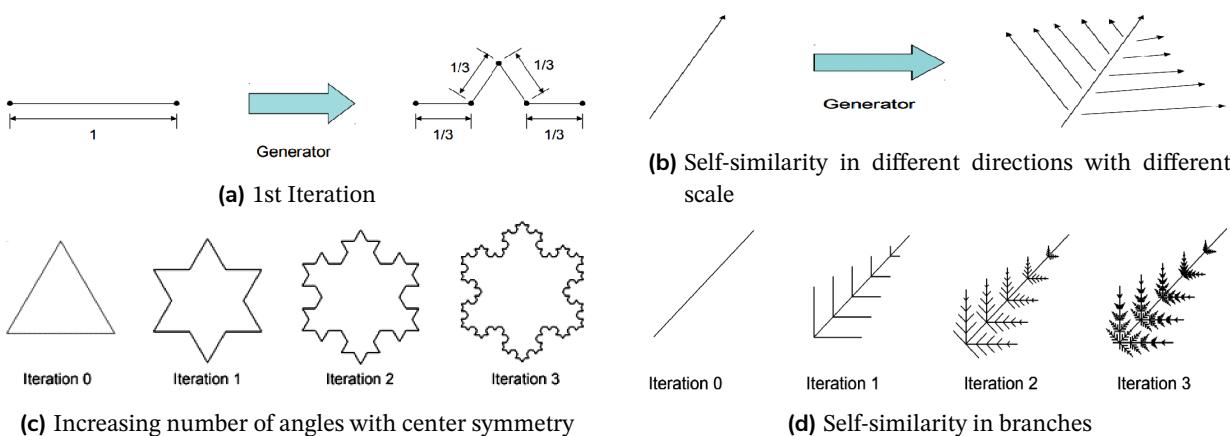
ates self-similar fractals which describe the existence of any entity as a part of whole or whole of several parts. The fractal architecture indirectly indicates human creation as a part of god. All the Hindu temple and its associated architectural designs are constructed as miniature forms of the infinite universe as enshrined in Hindu philosophy and beliefs.

Hindu Philosophy describes the cosmos as holonomic character which implies the virtue of self-similarity, homogeneity, isotropy and symmetries of various kinds. The holonomic characters are symmetric spaces arising in a wide diversity of conditions in both mathematics and physics. They are significant objects of study in representation theory and harmonic analysis as well as in differential geometry. At any fractal stage, each part of the cosmos is considered to be whole in it and to comprise information similar to the whole. The philosophical idea behind fractal is quoted in *Kaṭhopaniṣad* (4.10) as “Whatever is here, that is there; what is there, the same here.” The fractals indirectly indicate the existence of everything as self-similarity from whole to the part and vice a versa. It also indicates the permanent existence of wholeness.

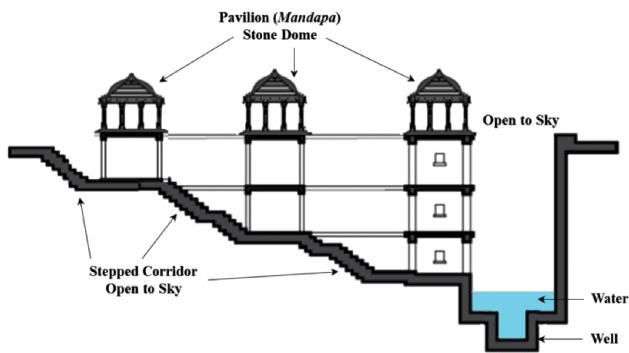
## 3 History of step wells and water tanks in India

A step well is a structure associated with well having staircase which facilitates access to water level in any season, as the water level fluctuates from high to low in monsoon to summer season respectively. The number of stairways is single in most of the wells, but sometimes a greater number of stairs are also planned and designated with traditional names as per numbers of steps (Appendices 1 and 2). The *kundas* are stepped water reservoir associated with religious pilgrimage places built for the purpose of holy bath during festivals or for routine worshiping (Figure 2). The *Mayamata* and *Mānasāra* are considered to be the earliest texts which describe the characteristics of water-monuments, like *kūpa*, *vāpi*, *taddga*. *Aparājītprchā* (chap. 74) classifies step wells into four types namely, *nanda*, *bhadra*, *jaya*, *vijaya*. *Bṛhatśilpaśāstra* (Book 3, v. 532), and the *Rājavallabha* (chap. 4, v. 28) provide the same information about the four types of step wells in very concise form (in one verse of two lines each).

Archeological survey of India discovered the oldest step



**Figure 1** Generation of Fractals after different iterations (Kitchley, 2014 CE, pp. 634–652).



**Figure 2** Typical step well component parts in longitudinal cross section.

well documented in history at Dholavira, Kutch, Gujarat in October 2014 CE. It is 73.40 m long, 29.30 m wide and 10.00 m deep, considered bigger than the size of Great Bath of Mohen-jo-daro (Figure 3). In western India the first step well and *kunda* were constructed as rock-cut structure at Dhank (550–625 CE) and stepped pond at Bhinmal (850–950 CE).

#### 4 Step wells in India

Traditionally, certain types of man-made water bodies (step wells) were designated as *jalamandira* (water temple) or *jalamahal* (water palace) in Gujarat. It is observed that the step wells were not only constructed within the urban or village area but even in far off places or on the connecting routes between cities. The depth, access points and the level of architectural beauty depended on

its status or association with ruler's family. The traditional or cultural name was given to each well depending upon number of entry points (Appendix 1). The number of exits for the step well increases with the diameter of the well. From '*nanda*' to '*bhadra*' opposite exit adds to the geometry, and from '*jaya*' to '*vijaya*' one more exit adds to the right angle. The typical design from '*nanda*' to '*vijaya*' follows the rules of symmetry. *Bolari vav* is a unique structure where upper diameter of the well is smaller than the lower stages of well.

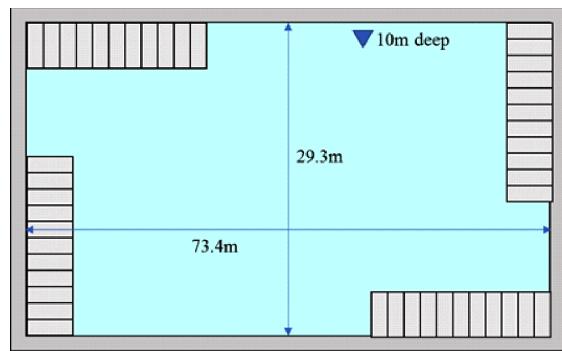
The *kundas* and step wells (*baolis* as regional name) were included uniformly across India to study the fractal concepts adopted in water conservation structures (Figure 4). The dimensional studies were carried out, typical geometrical plan was prepared and common attributes of the fractals were highlighted for each structure. It was found that geometry formation from bottom-up (lowest level to earth surface) generates the fractal geometry and repetition of the same fractals after uniform intervals.

#### 5 Fractal architecture of step wells

The step wells can be classified in three ways as per their geometry (i) Linear (ii) Circular and (iii) Rectangular or square. Based on architectural similarities they can be classified as pre-Mughal and post-Mughal. There is no evidence of construction of step wells after 1850 CE. The depth of step wells indirectly indicates the depth of water table at the time of its construction. The range of depth of step wells varies from 6.0 m to 30.0 m. The step well of '*Rani ki vav*', located in Patan city, North Gujarat contains



(a) Step well at Dholavira constructed before 5000 BCE



(b) Schematic diagram of step well at Dholavira

**Figure 3**

Source: Wikimedia Commons. <https://en.wikipedia.org/wiki/Dholavira#/media/File:Dholavira1.JPG>

**Figure 4** Step wells and *kundas* in India.

seven storeys and the bottom of well is at 32 m from the ground level. The depth of step wells may vary from single to eight storeys where the height of single storey can be 3.50 m to 4.80 m.

The depth and width of approach steps, number of entry points (approach), diameter and depth of well bottom are the factors analyzed for various step wells. The architectural design depends on the depth of ground water table and type of soil. The step wells before the Mughal period had carvings of idols and cultural motifs. Buddhist commandments had been carved as *śilālekha* inside the step wells. However, no carvings were found in the step wells constructed during Mughal period. But all the step wells constructed over a period of time exhibit a similar type of architectural plan and longitudinal cross sectional design.

### 5.1 Adalaj step well, Ahmedabad

The Adalaj step well also known as *Rudabai* step well is located in the village Adalaj, north of Ahmedabad city (Joshi 2017). The construction was started in 1485 CE by Waghela dynasty and finished by Muslim ruler Mahmud Begda in 1499 CE. The well is made of sand stone in Solanki architectural style, a blend of Islamic and Jain architecture. It is octagonal in plan having five storeys. The view in Figure 5a is from one storey below the ground level, where the elevation of *mandapa* creates scaled down self-similarity. Similarly, the number of storeys is so aligned in elevation that it creates fractal illusion as depicted in Figure 5b.

### 5.2 Chand Baori, Abhaneri, Bandikui, Rajasthan

Chand Baori (Figure 6a) built in the 10th century CE is situated in the village Abhaneri near Bandikui, Rajasthan. It is also called as *baoli* or *bavdi* (Shubhangi and Shireesh 2015). It is 30.0 m. deep consisting of 3500 steps built in stone masonry. All the three sides of the well descend to ground water level at an angle of 70° approximately. The dimensions of the steps remain same at every level, but staggered at every next level below and the same self-similarity is repeated in next stage below. The top view (Figure 6b) clearly exhibits the scaling down of the geometry from ground surface to water level, creating an illusion of scale down rectangles. The adjustment of lateral steps in triangular pattern is quite difficult to arrange even to

day for corners of the geometry. It is most complex design which was executed before thousand years.

### 5.3 Firoz Shah Kotla, Delhi

Circular Baori of Feroz Shah Kotla Fort, Delhi was built in ashlar and random rubble stone masonry by Ghiyas-ud-din Tughlaq in 1321 CE. The stone arches are smaller at stage one compared to stage two as shown in figure 7a and 7b. The circular passage was designed to reach the water level at stage one and the same shape and architectural form are repeated at stage two with larger diameter and more passage width. The self-similarity in circular form is expressed as the scaling up of the diameter from water to ground level with obvious symmetry with respect to center.

### 5.4 Agrasen ki Baoli, Delhi

The Agrasen ki Baoli, (Figure 8) named after Raja Agrasen of the *Mahābhārata*, is believed to have been built during the 10th century and reconstructed in 14th century by the Agrawal community which traces its origin to Maharaja Agrasen. The structure does find a reference in the 12th century Sanskrit work *Pasanahacariu* of an Agarawal poet Vibudh Shridhara who resided in Delhi during the reign of the Tomar king Anangpal-III (ruled CE 1151–80). Reference to this have been found in an old map dated 1868 CE at the National Archives of India in New Delhi. The step well in Karad, Maharastra is similar in architecture and both are built in brick masonry. The steps are descending at an angle of 30° approximately.

### 5.5 Hazrat Nizamuddin Baoli, Delhi

Hazrat Nizamuddin Baoli (Figure 11a) is situated in Nizamuddin west attached to the *Hazrat Nizamuddin Darwāshā*, built by Ghiyas-ud-din in 1321–22 CE. The Baoli was designed perfectly in circular shape and the steps are descending towards the center in a scaling down of circles in geometry. Figure 11c describes the surrounding structures and the cross-sectional view of the Nizamuddin Baoli with descending steps towards the center. Circle inside the circles is the form of self-similarity in reduced scale of fractals.



(a) Fractal illusion in elevation inside Adalaj step well, Ahmedabad.



(b) Fractal illusion of open to sky gallery in Adalaj step well, Ahmedabad.

**Figure 5**

Source: [https://en.wikipedia.org/wiki/Adalaj\\_Stepwell](https://en.wikipedia.org/wiki/Adalaj_Stepwell)

## 5.6 Helical step well, Champaner, Gujarat

The cultural heritage of the Gujarat has been woven in a literature and specific names were given to step wells according to size and other specifications. Helical well is situated in Champaner, Pavagadh in Panchmahals district, 40 km away from Vadodara. Figure 12a, 12b and 12c shows the top view, plan and its mathematical representation in the form of spiral respectively. It exhibits fractal in the form of spirals. It indirectly suggests the type of fractals that once originates from zero and then expands to infinity in the form of a spiral.

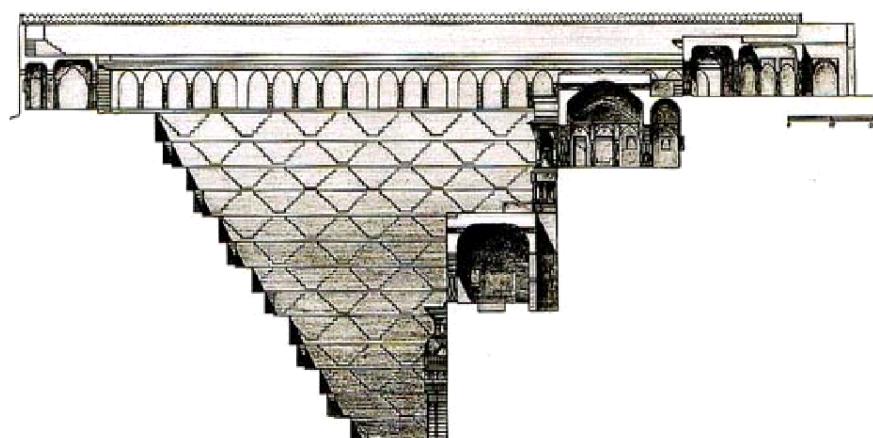
## 5.7 Chandrasekarapuram step well

The step well shown in Figure 13a is located at Chandrasekarapuram in Prakasam district of Andhra Pradesh. It was built in the 17th century and is source of pure drinking water within the fluoride affected region. It resembles base shape of *śivalīngam*, a very common shape of *śiva linga*. Approximate depth of water level from ground level is 7.50 m and maximum diameter is 18.50 m.

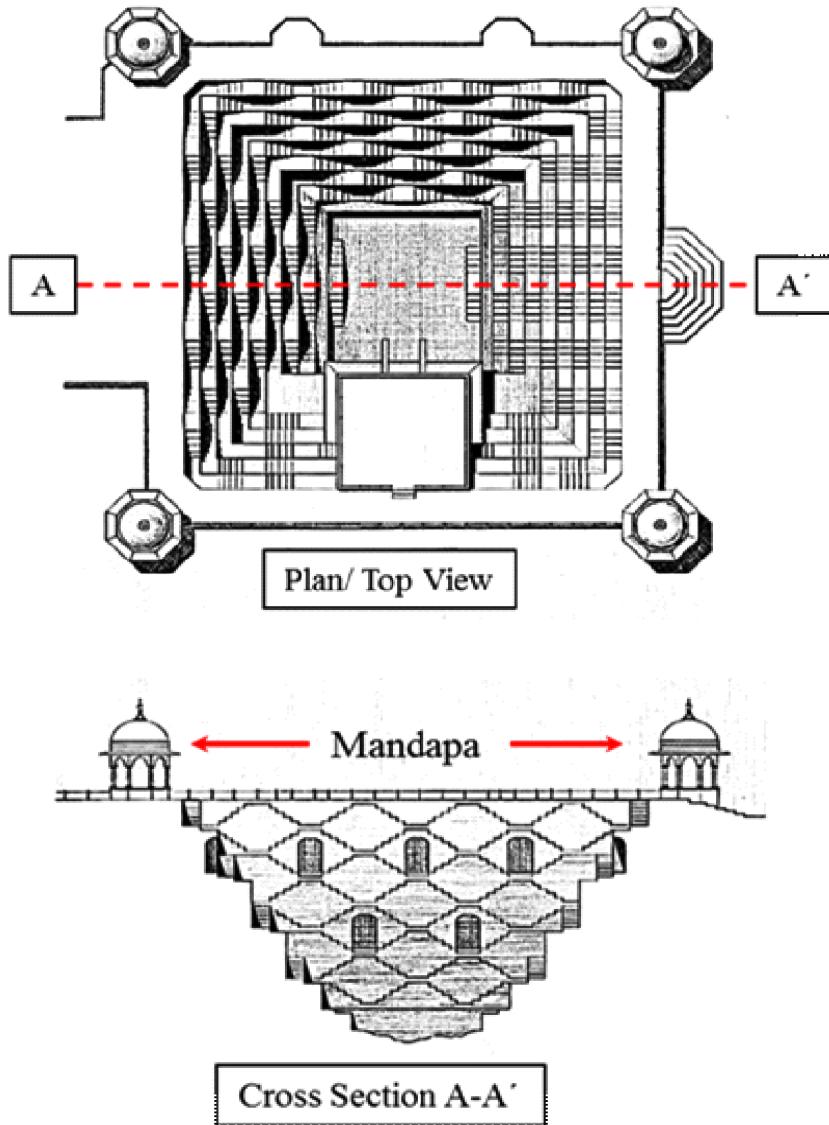
The steps leading to water level is 1.20 m wide and each flight contains 14 numbers of steps with approximate riser of 0.27 m. The location coordinates are, latitude:  $15^{\circ} 8' 58.49''$  N and Longitude:  $79^{\circ} 5' 33.65''$ . The shape of step well is unique in nature and the self-similarity of the shape is scaled down and extended to 8.0 m below ground level, but maintains the symmetry with respect to the line.

## 6 Architecture of tanks (*kunda*)

Indians have been ethnically sensible about the prized nature of water since the beginning of civilization. In the *nadisūkta* of the Vedas, the divine status has been given to *saptasindhus*. We have respected our rivers and water bodies as the perennial source of life. No pilgrimage is considered complete without a dip into one of the holy rivers or *puṣkarini*s (ponds) or *kunda* (tanks). Temple tanks are wells or reservoirs built as part of the temple complex. They are termed as *puṣkariṇi*, *kalyāṇi*, *kunda*, *sarovara*, *tālāba*, *pukhuri*, etc. in different languages and regions of India. Kirti Trivedi (1993, pp. 243–257) explained the importance of fractal architecture for water reservoirs during vedic period. The Sanskrit literatures describe classification of the reservoirs depending on the number of entry points, corners and stages to climb the water surface. The ancient names of such *kunda* (water tanks) are *bhadra*, *subhadra*, *nanda* and *paridhi*. *Bhadra* type of *kunda* comprises of simplest geometry, while *paridhi* type are complex in plan and design with increasing number of projections from the sides. In term of fractalization from line elements, first iteration leads to the *bhadra* type, second to the *subhadra* and third corresponding to *nanda*. It was noted that second stage of geometry with inner iteration starts in *paridhi* type *kunda* with typical geometry of repetition in fractal.

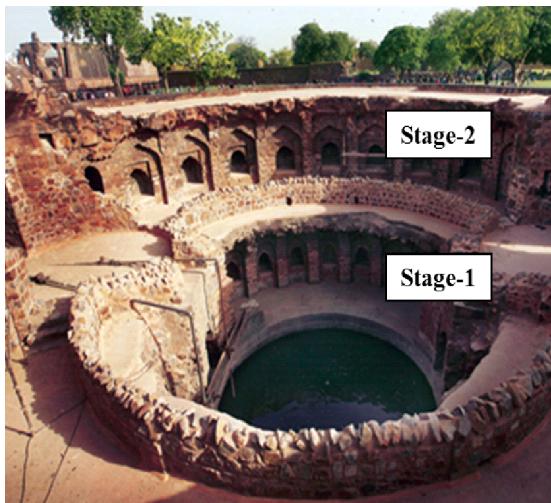


**(a)** Chand Baori, Abhaneri, Rajasthan.  
Source: <https://www.tresorsdumonde.fr/chand-baori/>

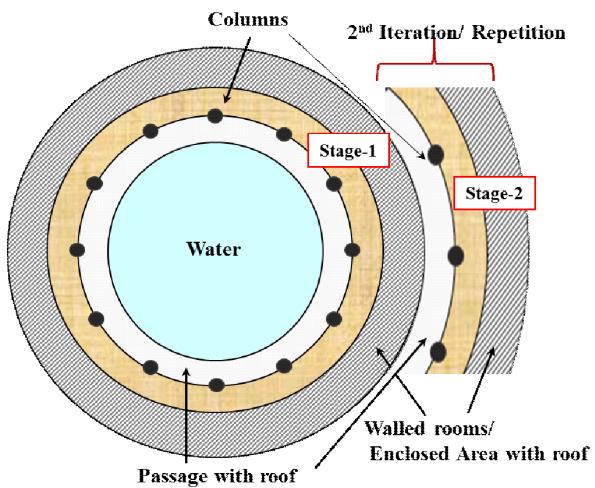


(b) Plan and typical cross section of Chand Baori.  
Source: Sketches: <https://in.pinterest.com/pin/119626933831362019/>

**Figure 6**



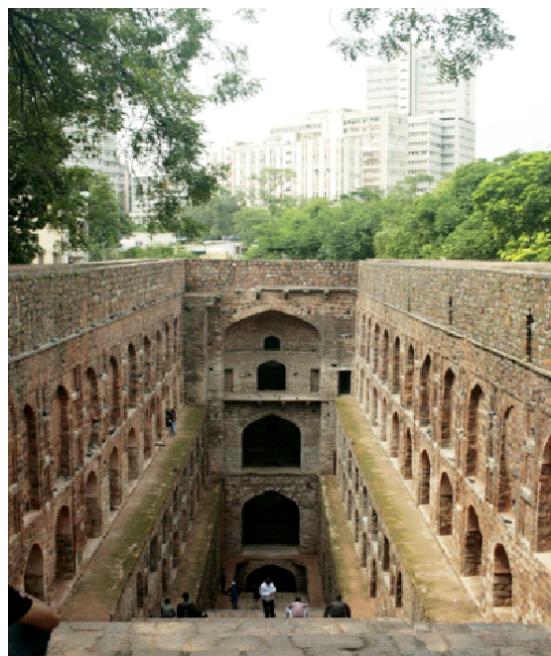
(a) Circular Baoli in Feroz Shah Kotla Fort.



(b) Typical plan of Circular Baoli.

**Figure 7**

Source: <https://www.dailyo.in/arts/history-of-delhi-glorious-cities-of-tomars-sultans-mughals-lutyens/story/1/25120.html>

**Figure 8** Agrasen ki Baoli, New Delhi.

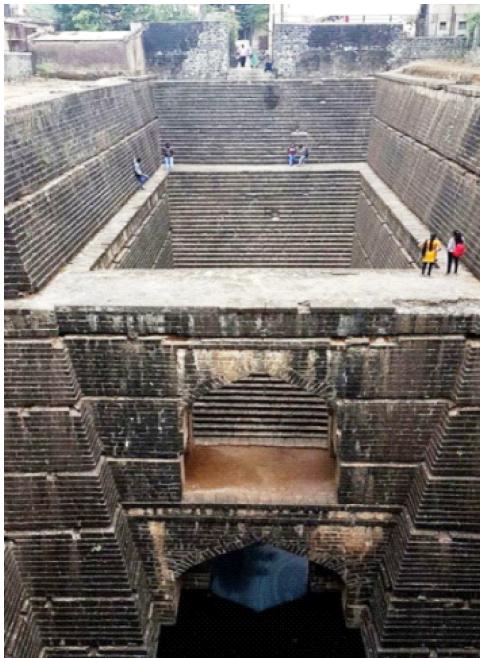
Source: [https://en.wikipedia.org/wiki/Agrasen\\_Ki\\_Baoli](https://en.wikipedia.org/wiki/Agrasen_Ki_Baoli)

### **6.1 Bhoga Nandeeshwara temple tank, Karnataka**

Bhoga Nandeeshwara Temple tank (Figure 15a) was built by the Ganga dynasty in 9th Century in Karnataka. It reflects Vijayanagar architectural style, where *mandapa* is decorated with repeated shrine like pyramidal structures of same size.

The columns of the *mandapa* are repeated equidistantly throughout the structure. The steps in a cluster of five are repeated after each landing with a width of 0.90 m. The temple tank is 76.20 m wide and 112.78 m long having entry points from all four sides. The depth of the tank is approximately 3.80 m. Here the geometry of the cluster of steps is scaled down rectangles and unique design is the repetition of the landings after group of five steps.

Almost all temples and monuments have water bodies attached to them. In Rameswaram, for instance, there are 22 water tanks inside the temple premises. The temple premises in Ujjain also contain more than 20 *kundas*. The Thar desert of Rajasthan had 84 *kundas* associated with an equal number of *tirthas*. In earlier times, there were more than 1,000 fresh water *kundas* in Mathura. The water was used for multiple purposes such as irrigation, domestic consumption, drinking purposes, bathing, etc. Due to rapid urbanization, lack of maintenance and prolonged negligence, 80 per cent of the *kundas* have silted up in the last 200 years and are on the verge of destruc-



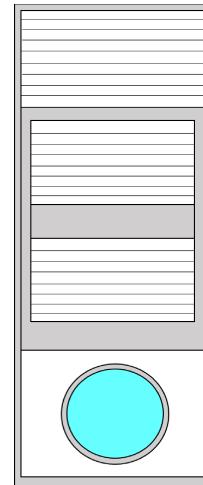
**Figure 9** Rawal's well, Karad, Maharashtra.

Source: <https://hinducosmos.tumblr.com/post/181216331352/naktya-rawalchi-vihir-ancient-well-karad>

tion. The depth of *kundas* ranges between 3.0 to 4.5 m and was designed in round, square, rectangle, hexagonal and in some unique shapes as well. The source of water for *kundas* may be a catchment area of several square meters to kilometers depending on the size. Very few of them have ground water as source of water. The architectural design of *kundas* differs from *baolis* or step wells in which hundreds of persons can reach to water simultaneously as compared to step wells.

## 6.2 Lakkundi, Karnataka

Lakkundi (1050–1200 CE) is a place of antiquarian interest with as many as 50 temples, 101 stepped wells (called *kalyāni* or *puṣkarīṇi*) and 29 inscriptions, spread over the period of the later Chalukyas, Kalachuris, Seuna and Hoysalas. There are numerous ancient wells in Lakkundi, of which the prominent ones being *Chateer Bavi*, *Kanne Bavi* and *Musukina*. *Chateer Bavi* well is 8.50 m deep with three side entry and one side entry for water from the perennial canal. It follows the symmetry with respect to line in longitudinal direction.



**Figure 10** Typical Plan of Agrasen ki Baoli and Rawal's well.

## 6.3 Sūrya kunda, Modehra, Gujarat

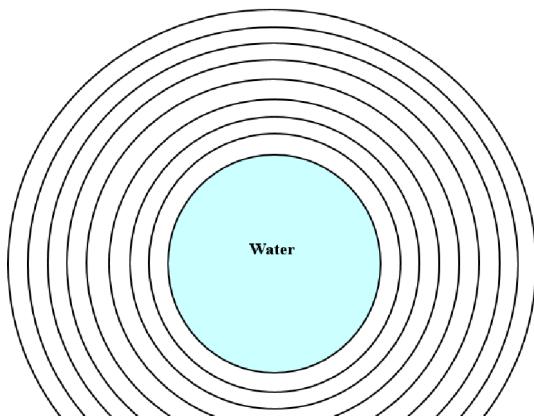
*Sūrya kunda* at Modehra Sun Temple (Figure 17a) was built during the reign of Bhimadeva-I of the Chaulukya dynasty in 1026–27 CE (Nisar and Ashraf 2009, pp. 34–39). The flight of steps leads to the reservoir or *kunda* through *kīrti-torāṇa* (a stone gate decorated by carvings). The *kunda* is rectangular in shape and measures 53.60 m from north to south and 36.60 m from east to west. There are four terraces and recessed steps descending to the bottom of the tank. The main entrance lies on the west. There are steps to reach from one terrace to another. These steps are rectangular or square except the first step of each flight which is semicircular. The geometry (Figure 17b) of the four terraces is self-similar architecture designed as scaled down design with respect to descending steps to water level in *kunda*.

## 6.4 Puṣkarīṇi, Hampi, Karnataka

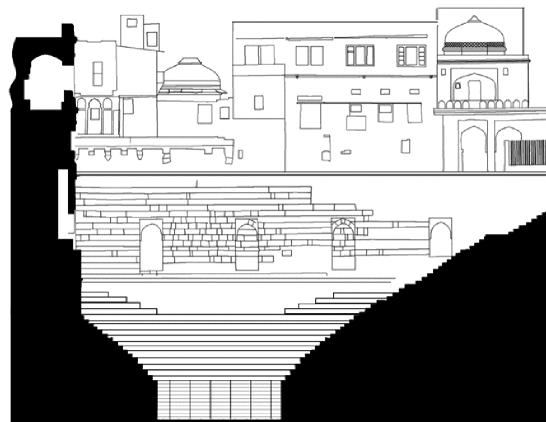
The Puṣkarīṇis of Hampi (Figure 18a) display great architectural beauty of the Vijayanagara style of architecture in 1565 CE. Many of these water tanks have beautiful rows of pillars or decorative arcades surrounding them. The massive water tanks have large stone steps that allowed people to get into the water easily (Water and Heritage 2018). The water tanks were fed with fresh water from the Tungabhadra River through an extensive network of stone aqueducts and canals. Some of these water channels are functional even today. The top view of Puṣkarīṇi



(a) Hazrat Nizamuddin Baoli, Delhi.



(b) Typical plan of Hazrat Nizamuddin Baoli.



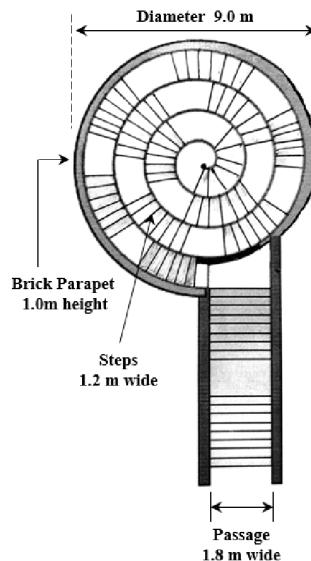
(c) Longitudinal Cross-sectional sketch of Hazrat Nizamuddin Baoli, Delhi.

**Figure 11**

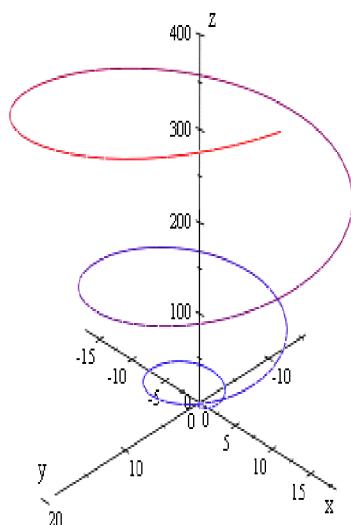
Source: <https://behtardilliblog.wordpress.com/2011/10/01/baoli-at-nizamuddin/>



(a) Helical step well at Champaner, Gujarat.



(b) Schematic diagram of Helical step well.



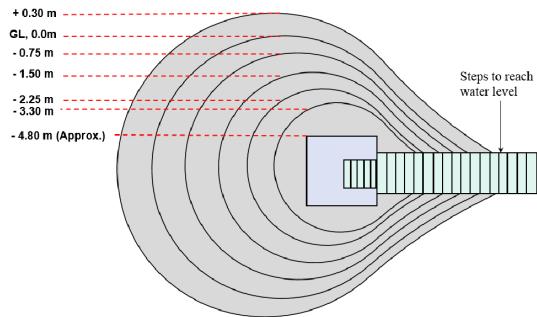
(c) Mathematical representation of log spiral equivalent to helical well geometry.

**Figure 12**

Source: <https://www.gujartourism.com/destination/details/6/166>



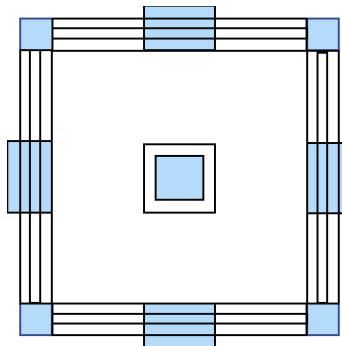
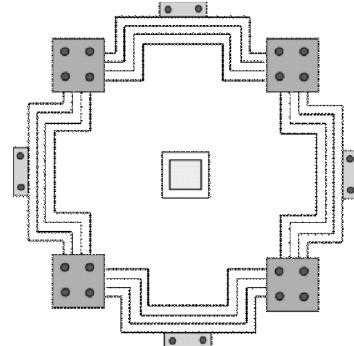
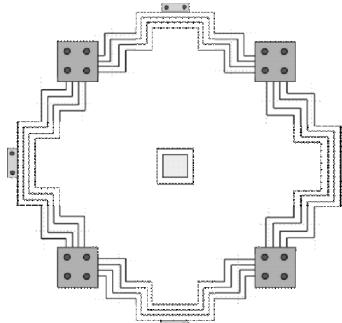
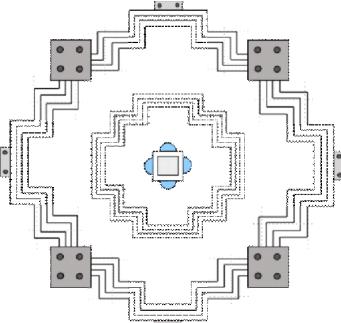
(a) Chandrasekarapuram, Prakasam, Andhra Pradesh.



(b) Plan view indicating different levels of decent from ground level.

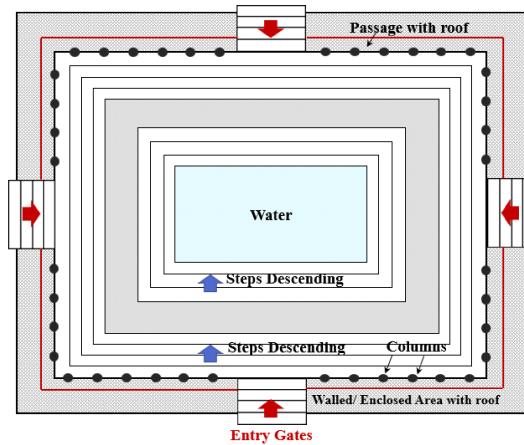
**Figure 13**

Source: <https://hinducosmos.tumblr.com/post/173216570042/an-old-horseshoe-stepwell-chandrasekarapuram>

(a) *Bhadra* (4-corners).(b) *Subhadra* (12-corners).(c) *Nanda* (20-corners).(d) *Paridhi* (20 corners + 12 corners in second stage)**Figure 14**



(a) Bhoga Nandeeshwara Temple, Nandi Hills, Bangalore.



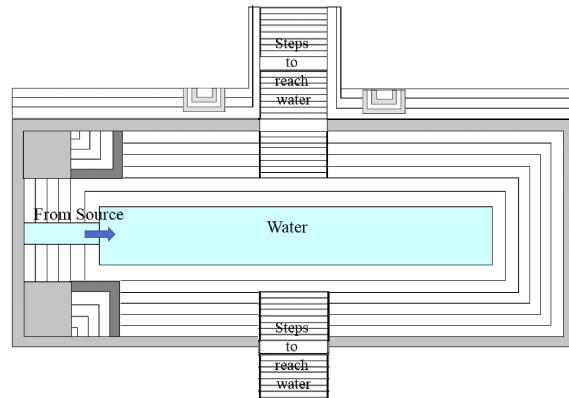
(b) Typical plan of Bhoga Nandeeshwara Temple, Nandi Hills, Bangalore.

**Figure 15**

Source: <https://www.karnataka.com/nandi-hills/sight-seeing-nandi-hills/>)



(a) Lakkundi, Karnataka.



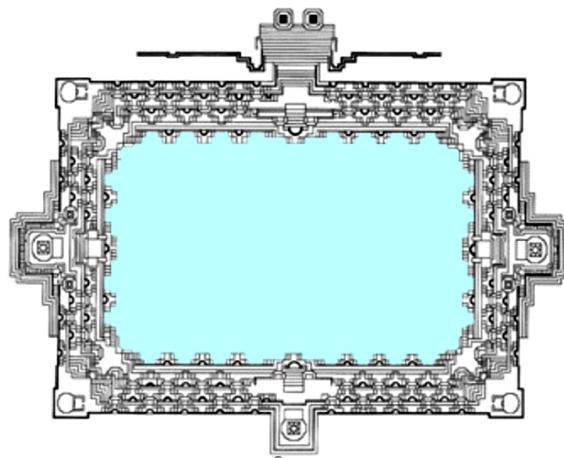
(b) Typical plan Lakkundi, Karnataka.

**Figure 16**

Source: <https://in.pinterest.com/pin/470555861047188342/>)



(a) Sun Temple, Modhera.



(b) Typical plan of Sun Temple, Modhera.

**Figure 17**

Source: <https://twitter.com/laxmikantmallya/status/932840474120830976>

of Hampi (Figure 18b) is similar to the Sūrya *kundā* (Figure 18b) of Modhera, and the same architectural design is found in more than 120 step wells and *kundas* (water tanks) throughout India.

The tank built in stone is a square structure with five steps. The steps become smaller as they go down. From the top, the length of each side of the step is 20.70, 16.10, 12.65, 9.20 and 6.90 m respectively. Each side has a very attractive pyramidal shaped flight of steps to get into the next lower level. These steps are 9, 7, 5, 3 and 1 respectively on each side and thus the entire tank has one hundred steps. Each tier is 1.05 meters and the total depth is 6.65 m. The base of the tank is embedded with sand filled stone slabs to purify the water. The symmetry of the pyramid shaped steps at each tier of the tank makes the structure unique and elegant.

### 6.5 Lolarka *kundā*, Varanasi

Lolarka *kundā*, Varanasi (Figure 19a) situated at Tulsi *ghāṭ* can be referred in *Kashi khanda* of *Skandapurāṇa*. It was renovated in 1941CE. It is mentioned that Lolarka is located at the confluence of the Ganges and Assi rivers. Currently the *kundā* is about 15.0 m below the ground level and steep stairs from three sides descend into the rectangular water pool. The water flows into a nearby well from an arc shaped gate on a high wall. The architectural design is symmetrical with respect to line and

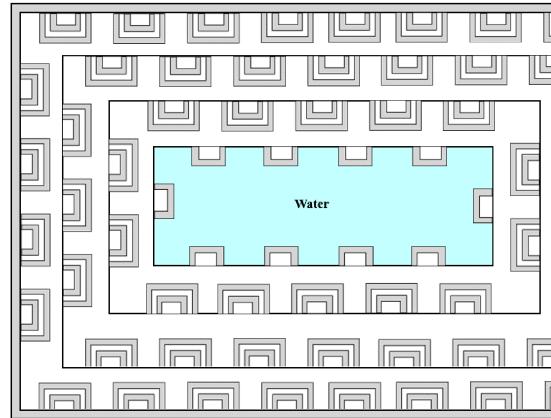
creates illusion of reduced scale rectangles to water level. The three stair ways in geometry creates the effect of branch fractals.

## 7 Analysis and Discussion

Step wells show fractals in terms of repetition of the architectural features like alternate arrangement of the pavilion, steps descending and open to sky areas. The descending steps more or less can be represented by golden ratio in the Fibonacci series. The self-similarity in architecture can be categorized as (i) unintended, when the fractal quality has been selected for an aesthetic sense (Hindu architecture), and (ii) intended, when the fractal component is, in every instance, the result of a precise and cognizant act of design (modern architecture). The complex geometry in all tanks (*kundas*) and step wells were artistically executed by gradual iterations using fractalization, self-similarity and repetition and superimposition. The rules of repetition and diminution act conjointly and almost ad infinitum (Figure 20). In step wells the repetition of *mandapa* is observed after every flight of steps and mostly steps are observed below the open to sky portions. In most of the cases the domes known as *chattarī*, in regional language are constructed on same datum line above ground level. The flat slab is supported by number of columns with different stages of slabs at respective da-



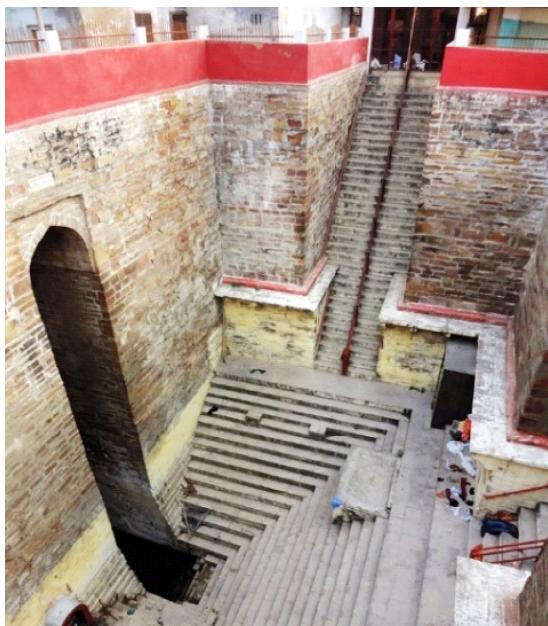
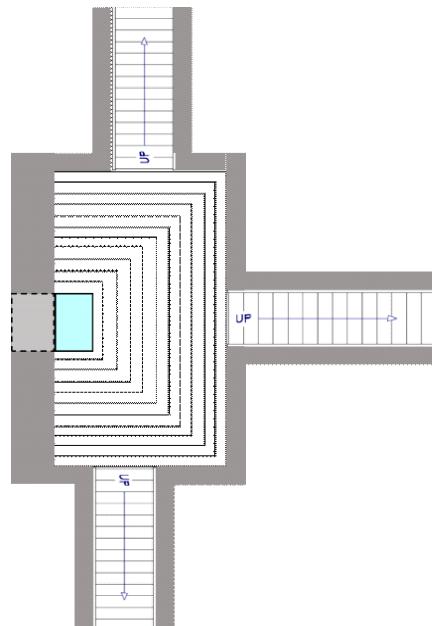
(a) Puṣkaraṇīs at Hampi, Karnataka.



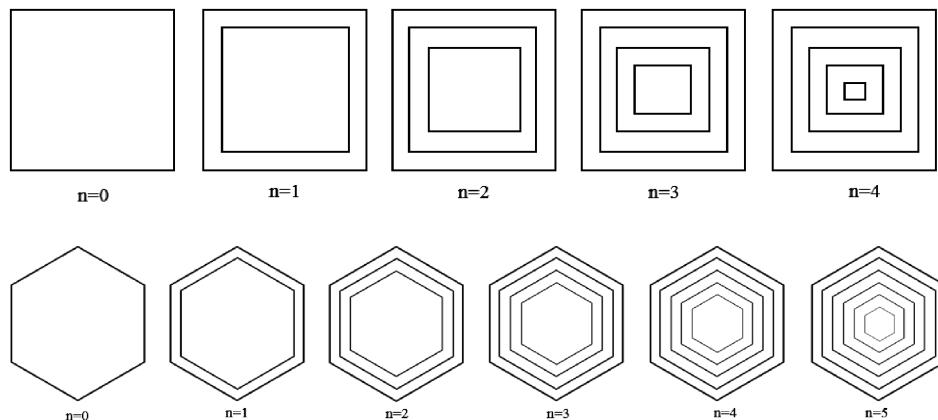
(b) Typical plan of water tank at Hampi.

**Figure 18**

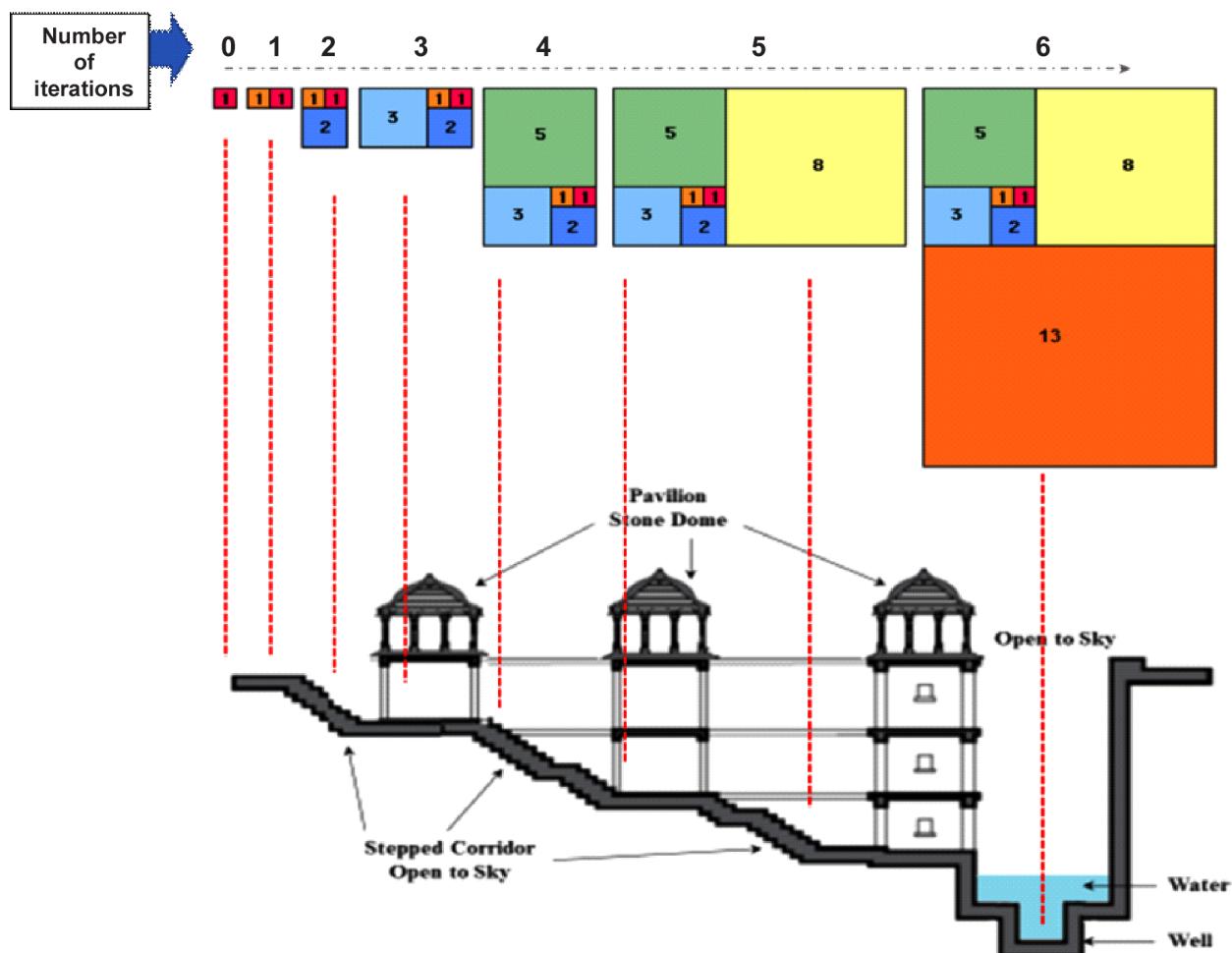
Source: <https://www.wallpaperflare.com/tank-hampi-unesco-monument-stepped-tank-karnataka-ancient-wallpaper-wotda>

(a) Lolarka *kundā*, Varansi.(b) Typical Plan of Lolarka *kundā*.**Figure 19**

Source: <https://in.pinterest.com/pin/554505772863388224/>



**Figure 20** Iteration process for self-similarity of different geometrical shapes (Sala 2006).



**Figure 21** Fibonacci iteration for step well geometry.

tum from ground level. The use of the Fibonacci series of complex and simple form is expressed in Figure 21. The complex geometry was observed in step wells which carried state importance or status associated with the kingdom. The normal series was observed in step wells not associated with status symbol of state.

## 8 Conclusion

The fractal geometry is used both unintentionally and intentionally in the field of architecture for supporting creativity in the ideation of new forms and for testing harmony between old and new designs. It helps define new architectural models and an aesthetic that has always lain beneath the changing artistic ideas of different periods, schools and cultures. The present study shows that it contributes significantly to a progressive transformation of the water structures to the optimization of space and their use, as well as to enhance their architectural beauty and accessibility leading to a better environment inside the structure. It allows the architectural planning and designing of the water structures according to hierarchy ordered centers which ensures a rational contribution of flows and a common human and environmental ambience and service supply.

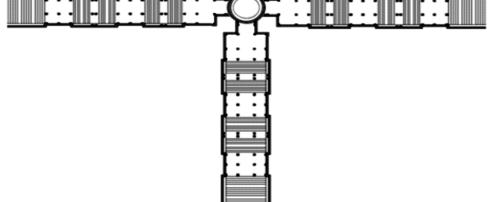
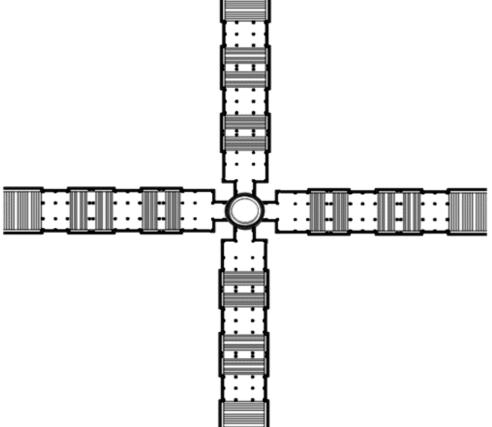
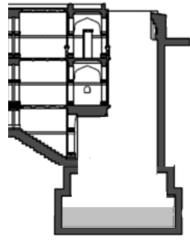
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**Appendix 1****Table 1** Step wells with architectural details.

Sr. No.	Name	Year of Construction (CE)	City/Area	No. of steps	No. of Columns	Angle of descent	No. of Openings to sky	Depth from ground level (m)	Horizontal length (m)
1	Rani ki vav	1052	Patan	120	62	22.87°	4	27	64
2	Ruda bai ni (Adalaj ni) vav	1485	Adalaj	125	270	12.5°	10	24	67.5
3	Dada hari ni vav	1499	Ahmedabad	120	180	13.2°	6	32	64
4	Bai Harir ni Vav	1499	Asarva	80	430	13.7°	9	30	60
5	Vadaj vav	1499	Ahmedabad	60	35	13.7°	6	22	63
6	Gandharva vav	1499	Saraspur	35	35	10.3°	6	8	82.5
7	Aashapura mata ni vav	1500	Bapunagar	70	180	14°	6	20	60
8	Khodiyar Mata ni vav	1600	Bapunagar	50	60	13.09°	4	24	64.5
9	Sindhvai Mata ni vav	1605	CTM, Ahmedabad	35	20	15.94°	3	13	51
10	Helical vav	1605	Champaner	> 85	0	> 32°	5	21	20
11	Amritvarshini vav	1723	Panchkuva	50	25	25.46°	7	14	30
12	Mata Bhavani ni vav	1866	Asarva	50	110	18.4°	6	17	45

**Appendix 2****Table 2** Cultural names of step wells for different diameter with their existing locations.

Sr. No.	Diameter of well	No. of exits	Cultural name	Place of provenance	Sketch
i)	0.75 m	1	<i>Nanda</i>	Bhavani Vav, Matar, Ahmedabad	
ii)	1.5 m	2	<i>Bhadra</i>	Dada hari ni Vav, Ahmedabad	
iii)	2.75 m	3	<i>Jaya</i>	Adalaj Vav, Gandhinagar	
iv)	3.5 m	4	<i>Vijaya</i>		
vi)	4.75m	1, 2 or 4	<i>Bolari vav</i>	The step well in which inner part is broader than the upper part, is called <i>Bolari vav</i> .	

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