

# Exploring Delhi Monuments Mathematically

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**DISTRICT INSTITUTE OF EDUCATION AND TRAINING**

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## *From the researcher's pen...*

As a representative of an organisation that strives for the upliftment of education by providing training and support to teachers and school education, I feel proud to correlate our heritage and development with the field of Mathematics. Through this research we tried to bring to your table, a cohort of interesting observations and exploration of monuments, traditional knowledge, culture and architecture interpreted through the lens of Mathematics.



The power of heritage makes the mathematical classrooms a better place of learning by relating it with our past.

It will help in drawing linkages between history and development of culture and civilization of a society.

I hope this research will erudite the facilitators and learners at various levels of curriculum and in achieving a high standard of knowledge. This will further reach out to academicians, universities and all knowledge seekers and will be a milestone in their journey of learning.

I would like to pay gratitude to Dr. Jyoti Sharma for her valuable contribution and suggestions in this research. I extend my gratitude to Dr. Davendar Singh Yadav, Dr. Ranjana Ruhela and the supportive faculty members and trainees for their support in collecting data. I pay my sincere thanks to INTACH for allowing me to assess their library and providing me supportive environment to explore books.

*Ruchi Sharma*

Dr. Ruchi Sharma



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# 1

## INTRODUCTION

India is a country of rich cultural heritage. It is a land of temples and monuments with magnificent architecture. These various temples and monuments reveal the history of Indian civilization and narrate the story of evolution of India across various periods and dynasties. These buildings are not merely the structures illuminating the history but the culmination of brilliant intelligence and practical knowledge of space and shapes. The designing and edifice always fascinated the researchers and forced them to unfold the knowledge lying beneath these standalone excellences transcended into timeless marvels of our heritage. They use various lenses to explore the arrangements used in a particular structure to understand them and appreciate them from various perspectives. Some scholars took up the temples while some explored the monuments and some tombs according to their interest areas. Yet, all the structures are unique and are indeed wonderful examples of transcending knowledge into its best irrespective of time. Prof. Rao (2022) studied architecture of Indian temples and stated that these structures are the combination of wisdom and practical knowledge and exemplary of putting manifestation into physical reality. Savita in her work on tombs analyzed the structures of tombs in terms of architecture, location, epigraphic and decoration. She observed a shift in the structures of tombs in early and middle Sultanate period to the late Sultanate period and stated the reason of change, the changing socio-political conditions. Azmat and Hadi (2018) studied the geometrical patterns and designs dominantly used during the Mughal period. They stated that in pre- Mongol period a lot of experimentation with geometric figures were done to create various fascinating patterns on walls, floors, corners that add to the beauty of structure and also

provide strength to it to stand tall for decades and centuries to come. The dominated geometrical structures in Mughal dynasty stated by Azmat and Hadi (2018) are various polygons- predominantly even sided polygons, like hexagon, octagon, decagon. These polygons were restructured to form even sided stars in a pattern of jalis on windows and flooring. Such ornamental patterns can commonly be observed in the Islamic architecture in Mughal structures. This article ponders on the mathematical concepts like radical symmetries, polygons, overlapping polygons and special combinations of pentagons and squares named as tympanum.

Similarly there are many more researchers who research on these historical buildings and try to find out not only historical facts but also the underlying philosophy of the frame of the structure as well as the mathematical experimentation and exploration done during that period of time. Drawing knowledge from these archival sources is miraculous. Analyzing the patterns, exploring the combinations of 2D and 3D shapes, observing and understanding the structure that is a combination of various sub structures. Studying the experimentation with the various shapes make these structures a lively example of “embodiment of mathematics” in all spheres of life.

The researches in this field provide opportunities to re-evaluate the cultural significance of a monument or building in the domain of histories of art, mathematics, and architecture. They are the collaboration of mathematical and artistic minds. And getting deep in these structures reveal that they have been based on different formulas or concepts as Cha & Kim (2020) stated in their ethno study. They found that carpenters used to apply Yingzao Fashi’s formula in constructing an octagonal shape using a ratio between the square and its diagonal which is very different from the usual method.

These researches and articles state that mathematics is omnipresent and an essential part of daily life and a culture. Monuments, religious buildings, textile, food and even the technology has the strong grounding of mathematics, and together they give a picture of intertwined mathematics in a variety of practices all over a day (Rossi & Corinna; 2009).



## OBJECTIVES

- To identify and appreciate cultural and historical aspects of Mathematics.
- To understand mathematical ideas embedded in historical monuments.
- To understand mathematical ideas in art, art forms and aesthetics.
- To integrate mathematics with history, art forms and culture.

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## 2

## METHODOLOGY

The study “Exploring Delhi Monuments Mathematically” proposed the analysis of monuments from a mathematical perspective. Monuments are the structures of remembrance of history reflecting the culture of a particular time period of history. The study of these cultural aspects in terms of mathematics to express relationships between culture and mathematics is termed as ethnomathematics. The purpose of ethnomathematics is to explore and appreciate the connection between the culture and mathematics embedded in that culture (wikipedia). This research also revolves around the idea that different forms of mathematical thinking led to different forms of mathematics and its implementation. This research studies the mathematical ideas used in different monuments created in different dynasties or eras and focuses mainly on the designing & architecture used in monuments. Thus, the nature of study looks into architecture of history and culture, so it is an ethnography or ethnomathematics study. Being ethnography, it is qualitative in nature.

### SAMPLE OF THE STUDY'S

Delhi itself has a rich cultural heritage of monuments. These monuments reveal the history of Delhi and its development in various eras. Thus, the population for the study was all the monuments of Delhi, which are around 174. which are (listed on this site) [https://en.wikipedia.org/wiki/List\\_of\\_Monuments\\_of\\_National\\_Importance\\_in\\_Delhi#:~:text=174%20Monuments%20of%20National%20Importance,by%20the%20ASI%20in%20Delhi](https://en.wikipedia.org/wiki/List_of_Monuments_of_National_Importance_in_Delhi#:~:text=174%20Monuments%20of%20National%20Importance,by%20the%20ASI%20in%20Delhi).

For this research we randomly selected the 10 monuments of Delhi for visit using an online random selection tool. We took the serial numbers listed on the above-mentioned site and mentioned numbers 1 to 174 from which selection was done. The sample to be selected was 10. Then we received the random numbers. The monument on the respective serial number was taken up as the sample for the study.

*The monument selected for the study were as follows:*

Sl. No.	Monument	
1	Ugrasen Ki baoli	14th Century
2	Tomb of Sarai Shanji	15th Century
3	Rai Pithora Fort	1060 CE
4	Qutub Minar	1199
5	Tomb of Sultan Ghari	1231AD
6	Tomb of Sikhandar Lodhi	1517
7	Humayun Tomb	1570
8	Lotus Temple	1986

Then a visit was planned to the selected monuments. The observers were oriented about the visit and the tools to be used for the study. Then the schedule for the observation was planned in the month of July.

## TOOLS OF THE STUDY

Tools play a vital role in a study for proper and authentic collection of data. Here also tools played a vital role in data collection. The small teams of observers visited the monuments. But the point of consideration was

The tools used in the study were

- Observation tool
- Reflections from the observers.

- **Observation tool:** Observation tool was developed by the researcher. It was a self-made tool and was based on a pilot study conducted on the same topic. The questions were designed to direct the observer to observe the structure in terms of mathematics focusing on the objectives of the study. The tool was validated by experts. The tool was presented to the observers beforehand.
- **Reflections from the observers:** The observers were made to give a right up on the monument they have visited and reflect on their experience considering mathematical aspects used in the respective monument. The purpose of these reflections was to get data in the observers' terms so that a complete picture can be derived from the combination of observation tool and reflection.

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# 3

## ANALYSIS

The analysis of historical buildings had a purpose of deep diving in the architecture, designing and underlying concepts of culture with the vision of mathematical understanding and its use in creating these unique structures. This research is descriptive in nature with a qualitative approach. It describes each monument (selected as a sample) in the light of mathematical aspects. As the data collection used in this research are observation and reflections from the observer. Observers have also collected pictures as annotations.

The data analysis technique involved the analysis of the building in terms of mathematical calculations and design principles that use algebra, geometry (like shapes and designs based on shapes, symmetry), mensuration in terms of dimensions and area of structure, numbers in terms quantity of openings or structure or shape used in designing and trigonometry. Analysis is monument based initially, where various aspects of designing and structure are analyzed in the light of mathematical principles.



## AGRASEN KI BAOLI



**Location :** Agrasen Ki Baoli is a well-known ancient step well also known as *Agrasen Ki Baoli*. Baoli of Agrasen in New Delhi. This historical step well is 60-meter long and 15-meter wide and is located on Hailey Road, near Connaught Place, Jantar Mantar. It is a protected monument by the Archaeological Survey of India (ASI) under the Ancient Monuments and Archaeological Sites and Remains Act of 1958. It is one of the best preserved Baolis in Delhi.

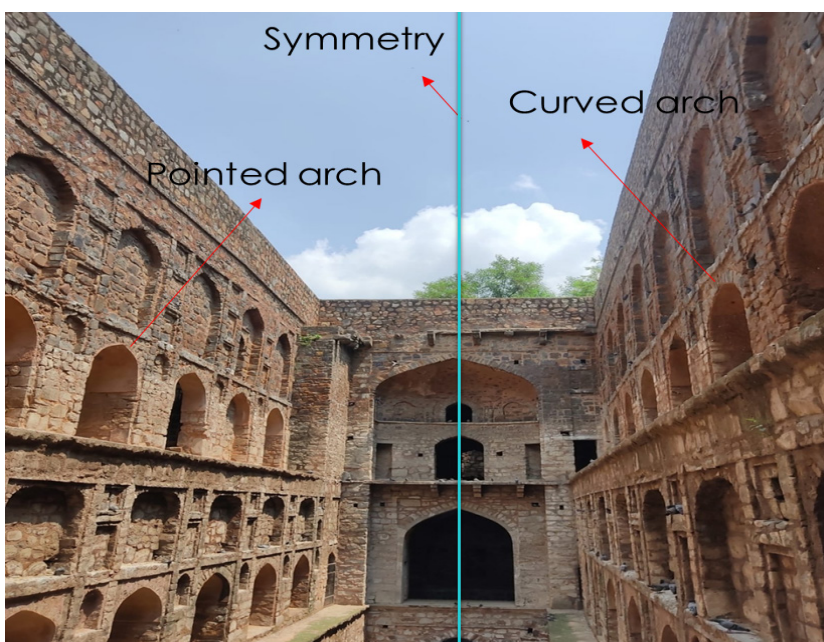
**History :** From historical perspective Agrasen Ki Baoli is among one of the oldest monuments of Delhi. But as such no records are available about the history of this stepwell. Its development is credited to the legendary king Agrasen, and the present architecture hints at it being rebuilt in the 14th century during the Tughlaq or Lodi period of the Delhi Sultanate. The main purpose of constructing this Baoli is not only to store water but also it was a place for women to assemble and spend some time in a cool place during scorching summers. Being quite deep it was a cool place for the travelers.

**Material:** The material used in the construction of Baoli is Red stone. It has about 108 steep steps all over. The whole building is a structure of red stone which is standing strong till day.

## Mathematics and architecture:

Agrasen ki Baoli is an ancient step well and is an architectural piece. The structure of this step well is based on the fractal geometry.

Fractal geometry as stated in the article by Tech Target Contributor “is a non-regular geometric shape with the same degree of irregularity at all scales. It can be perceived as never-ending patterns. Fractal has infinite patterns of similar iteration at different scales. This makes fractal a complex



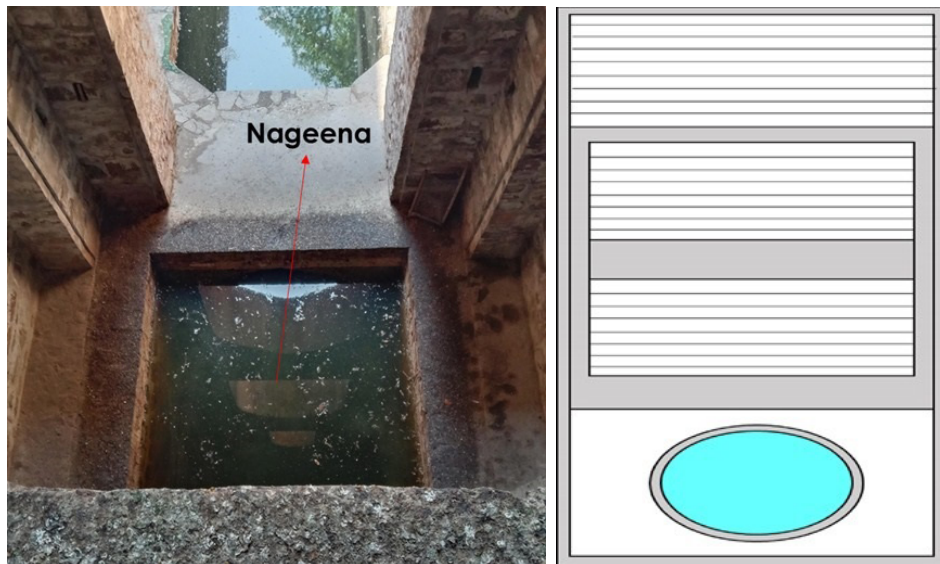
pattern. They are created by repeating a modest process repetitively in an ongoing feedback loop (<https://en.wikipedia.org/wiki/Fractal>). And it has provided beauty to the architecture of this monument.

The series of Chambers on the passage is an example of fractal geometry. Both the sides besides stairs are completely identical to each other. The vertical line divides the monument in two identical parts and reflects symmetry in the front arch as well as both the parts besides the symmetry line.

Boali can be visualized in 3 levels. Each level is ornamented with symmetrical arched niches on both sides of walls of the well. The walls have openings which help in maintaining the ventilation and temperature in it. The wall in front of the stairs has 3 arch shapes in which the top most is smaller and the rest 2 are congruent. The arches used in this monument are true arches.

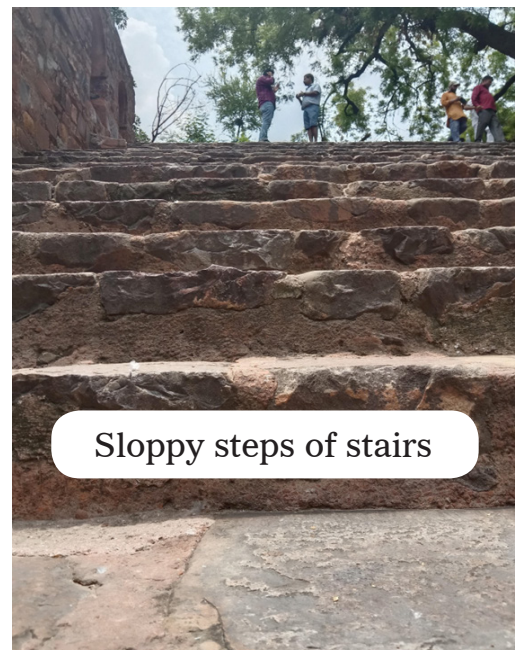


The typical structure of the stepwell has 3 wells, the outer one is considered rectangular in shape though it has 5 sides, then next to it is circular in shape and the innermost is in square shape. The innermost is also known as Nageena.



## RECTANGULAR STEPWELL IN AGRASEN KI BAOLI

Out of the 3 wells the rectangular stepwell is 60 meters in length and 15 meters wide. The rectangular shape of the stepwell makes it stand out from the other baolis in Delhi that were built as round water reservoirs.



Sloppy steps of stairs

## AREA OF THE RECTANGULAR STEPWELL

- LENGTH OF THE RECTANGULAR STEPWELL 60 -m
- BREADTH OF THE RECTANGULAR STEPWELL 15-m
- AREA OF THE RECTANGULAR STEPWELL- LENGTH X BREADTH  
=  $60 \times 15 = 900$  square metre

## CIRCULAR WELL IN AGRASEN KI BAOLI

The steps of the well are made with a slope so that water could not hold on the step.

A circular well exists at the northern end of this stepwell. It is around 150 ft deep and is the diameter of 8 meters. During monsoon season water can be seen in this well and the water level rises to a height of around 4 to 5 feet. Nowadays it has been covered with an iron grill to prevent any accidents. All the 3 tanks or wells are interlinked. As the water level rises it floats to the next tank. And this is how this baoli till today preserve rain water and maintain the water level for the community near to it.

## AREA OF CIRCULAR WELL

- DIAMETER OF CIRCULAR WELL- 8m
- RADIUS OF CIRCULAR WELL-  $8/2 = 4$ m
- AREA OF CIRCULAR WELL =  $\pi r^2 = 22/7 \times 4 \times 4 = 50.2\text{m}^2$



## AREA OF AGRASEN KI BAOLI

AREA OF AGRASEN BAOLI = AREA OF RECTANGULAR STEPWELL + AREA OF CIRCULAR WELL



$$= 900\text{m}^2 + 50.2\text{m}^2 = \mathbf{950.2\text{m}^2}$$

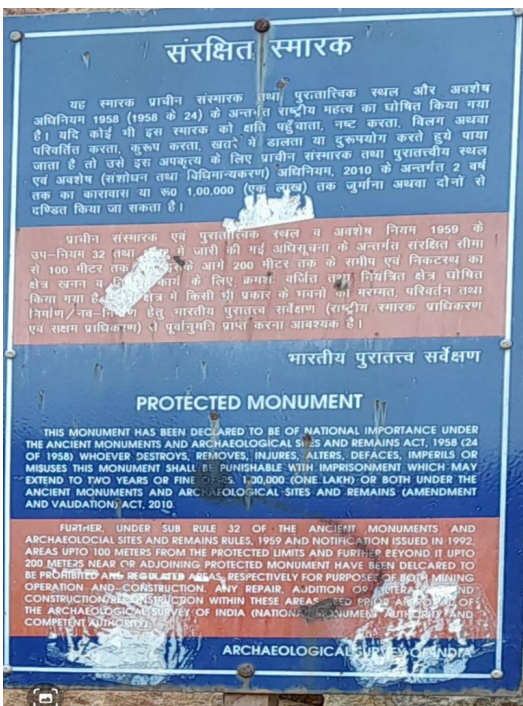
## SUPERIMPOSED ARCHES



The Baoli is a great example of superimposed arches as here one arch is placed over the other. At each level there are superimposed arches with rectangular base. At first level 15 arches are well spaced whereas at second level 16 arches and at third level again 15 arches are spread along the walls.

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## Tomb of Sarai Shahji



**Location:** The Sarai Shahji is located in

**Location:** The Sarai Shahji is located in South Delhi on Geetanjali road near Malviya Nagar. On the name of this palace the village area located around it was named Sarai Shahji village and was very much part of kingdom. As the name Sarai means inn which were meant for travelers to take rest during their travel. This structure is expected to be built in Mughal period. Though most of its part is encroached by the factories near it.

**History:** Sarai Shahji was built in Mughal era during about 15<sup>th</sup> Century. It is meant for the faraway travelers who found shelter here. It is one of the oldest structure in Delhi.

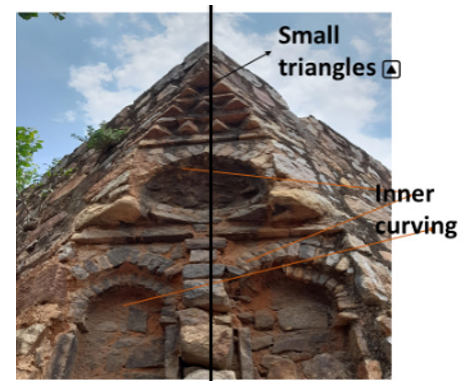
**Material :** The Material used in the structure is local quartzite stones and sand.



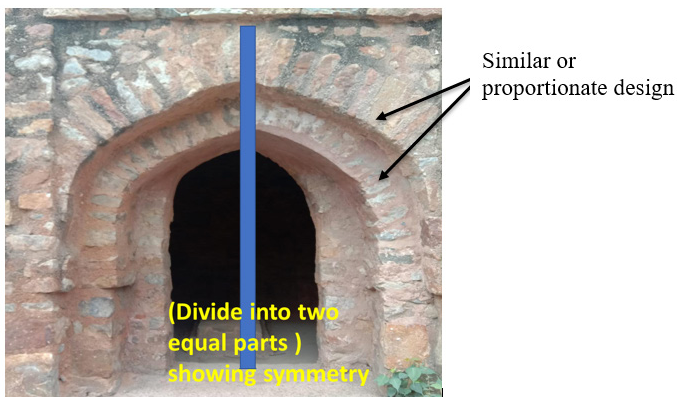
## Mathematics and architect:

As it is an oldest structure and much of its part is encroached so it is mostly demolished. The building is rectangular in shape with open large courtyard. In the courtyard one can see the graves which shows that it might be a graveyard which are usually created outside the city. Thus it was an outskirts area of the village or city. This courtyard is surrounded by an arcade. In the west of the structure lies 3 compartments which are roofed with pyramid shapes. This pyramidal roof gives the building a uniqueness and distinctive look from other monuments of Mughal period.

The building stands on the 12 pillars. These pillars are unidentical in design. 6 marble pillars of portico of the mosque stand apart from the design. The three-story tower next door has been beautifully constructed and has inspirations from both India and the Middle East.



The structure besides the pyramids has curved shaped wall. To support this structure a squinch can be seen. The squinch is decorated with a true curve and design of 10 triangles which reminds of Pascal's triangle. This structure is further supported rectangular slab and a pillar made of stones. This reflects the wonderful combination of solid shapes. This wall of Sarai shah ji contains the perfect example of vertical symmetry.



The entry gates show vertical symmetry in a rectangular frame. The similar or proportionate arches made of true curves design is visible at the entrance. The entrance is 3 layered and represent the similarity among all the three layers.

The top of the wall contains the three pyramids. These are rectangular

pyramids. The base of each pyramid is equal to the width of the rectangular frame situated just below it. The three pyramids are non-identical in size. Even the peak of one of the pyramids is destroyed. There is another cuboid structure on the top of which 4 solid half – cylindrical shapes were created.



The outermost walls of Sarai Shah Ji contained congruent structures of openings in a rectangular frame. Each rectangular frame has superimposed true arches. From each openings the grave is visible as it is placed in the middle of the compound considering the dimensions of the door.

The square pyramid structure when visualized from inside seems like a hollow pyramid and frame a quadrilateral base is visible in the given figure. It is very different from the other tombs as usually tombs have hemispherical shape of top rather than the pyramid shape.



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## RAI PITHORA FORT



**Location:** Quila Rai Pithora is situated near the Qutub Minar near Mehrauli. **The coordinates in which it is situated is  $28.52^{\circ}\text{N } 77.18^{\circ}\text{E}$  ().**

**History:** Getting into the history, Rai Pithora Fort was built in Tomar dynasty by Anangpal 1052. It was named “Lal Kot” by him. In 12<sup>th</sup> century it was captured by Prithviraj Chauhan (1149-1192). He expanded his city and renamed it as Rai Pithora. It is also known as ‘Quila Rai Pithora’, and it is also known as the first city of Delhi. During his regime Prithviraj made sixty-seven temples. Which were demolished and destroyed by the Gazni. Many remaining loke pillars and structures were used by him to build the mosque still present in Qutub Complex.

**Material:** It was the first Delhi tomb to be constructed of red stone.

# Mathematics and architect

The first ever fort of Delhi known as Qila-I-Rai Pithora, has seven gates. The wall of fort has very uneven spread in terms of its thickness i.e. 28-30 feet. It has been built in oblong shape, and spreads over a circumference of 2.25 km.



The structure of the fort contained structures of congruent openings in a rectangular frame containing ogee arched designs.



The outermost boundaries of the fort are round bastions. A bastion is a structure projecting outward from the curtain wall of a fortification, most commonly angular in shape positioned at the corners of the fort.

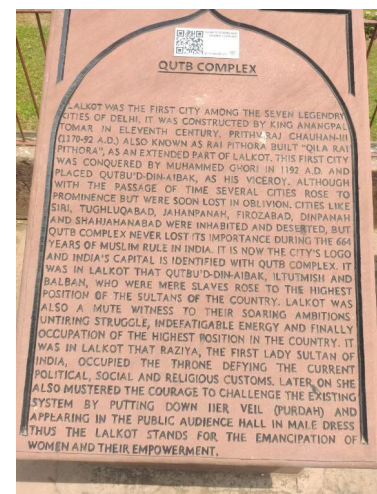
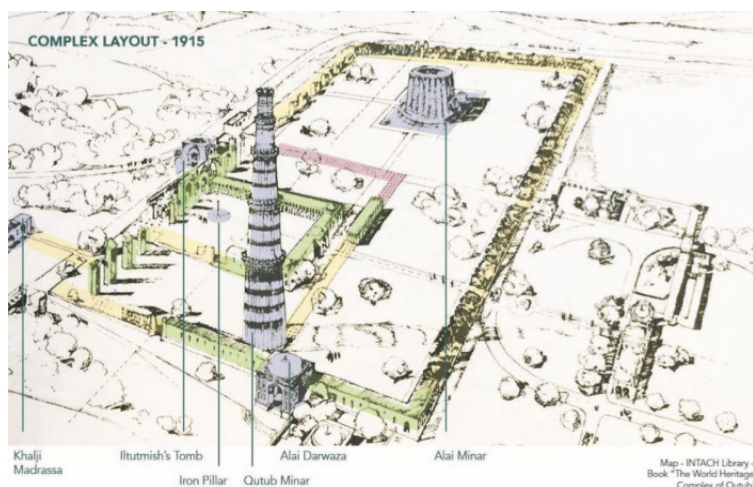


## QUTUB MINAR



**Location:** Qutab Minar, worlds tallest brick structure, located in South Delhi, Mehaurali and is also known as Qutab Complex. The Qutab Complex is a complex having various structures as Qutub Minar, Alai Darwaza, Iltutmish Tomb, Imam Zamin's Tomb and Alai Minar.

**History:** Qutab Minar built near Quwwat-ul-Islam Mosque in 1200 by Qutb-ud-Din Aibak. Its foundation was laid in 1199 in medieval period. It is also known as victory tower. It is created on the place of Delhi's oldest fortified city called Lal Kot, founded by the Tomar Rajputs.



**Material:** The material used in the complex is again a combination of Red and white stone. The Minar is made up of red and buff sandstone.

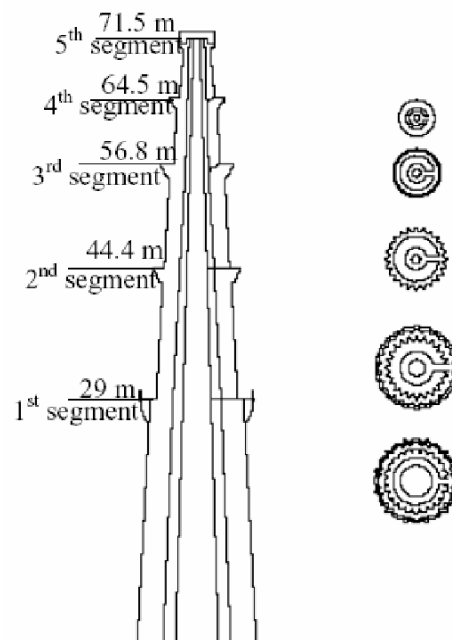
# Mathematics and Architecture:



Qutab Complex as stated above is a multiplex of two minars, two tombs, a mosque and a gate. As it is a medieval period structure, it has more of Hindu iconography used in the structures of the building which were the remains of the temples.

## Qutab Minar:

The world tallest brick structure is known for its height which is 72.5 meters (238') and diameter of bottom is 14.32 meters (47'.3ft) and top diameter 2.75 meters (9ft). At a particular time, the length of the shadow of Qutub Minar whose height is 72 m is 80 m. Shape -Qutub Minar is in the shape of a cone with a flat top called a frustum. It has five stories with intricate carvings and geometrical patterns.



([PDF] Seismic Vulnerability Assessment of Qutb Minar, India | Semantic Scholar (<https://images.app.goo.gl/LZaNHGYHn1B48Hr27>))



The tower originally was four storied high with a domed roof. In 1369, a lightning strike destroyed the top story. Firoz Shah Tughlaq replaced the damaged story and added one more.

The tower is entered from a gateway on the north side which opens out into a spiral staircase. There are 379 steps in all.



Each storey has a different pattern in plan.

- First storey -Alternate wedge shaped and round projections
- Second storey -Circular projections
- Third storey -Star shaped
- Fourth storey -Round Balconies

Each storey has a balcony around it. The balustrade around the balcony originally showed merlons called kanjuras. The balconies are supported by stalactite vaulting, represented by clusters of miniature arches with brackets in between, influenced by the tracery of temple ceilings.

The tower has five superposed stories. The lowest three comprise **fluted cylindrical shafts or columns** of pale red sandstone, separated by flanges and by storeyed balconies, carried on Muqarnas corbels. The fourth column is of marble and is relatively plain. The fifth is marble and sandstone.

The flanges are a darker red sandstone throughout and are engraved with Quranic texts and decorative elements. At the foot of the tower is the Quwat ul Islam Mosque. **The minar tilts just over 65 cm from the**

**vertical**, which is considered to be within safe limits. Qutub Minar was an inspiration and prototype for many minarets and towers built. The Chand Minar and Mini Qutub Minar bear resemblance to the Qutb Minar and are inspired by it.

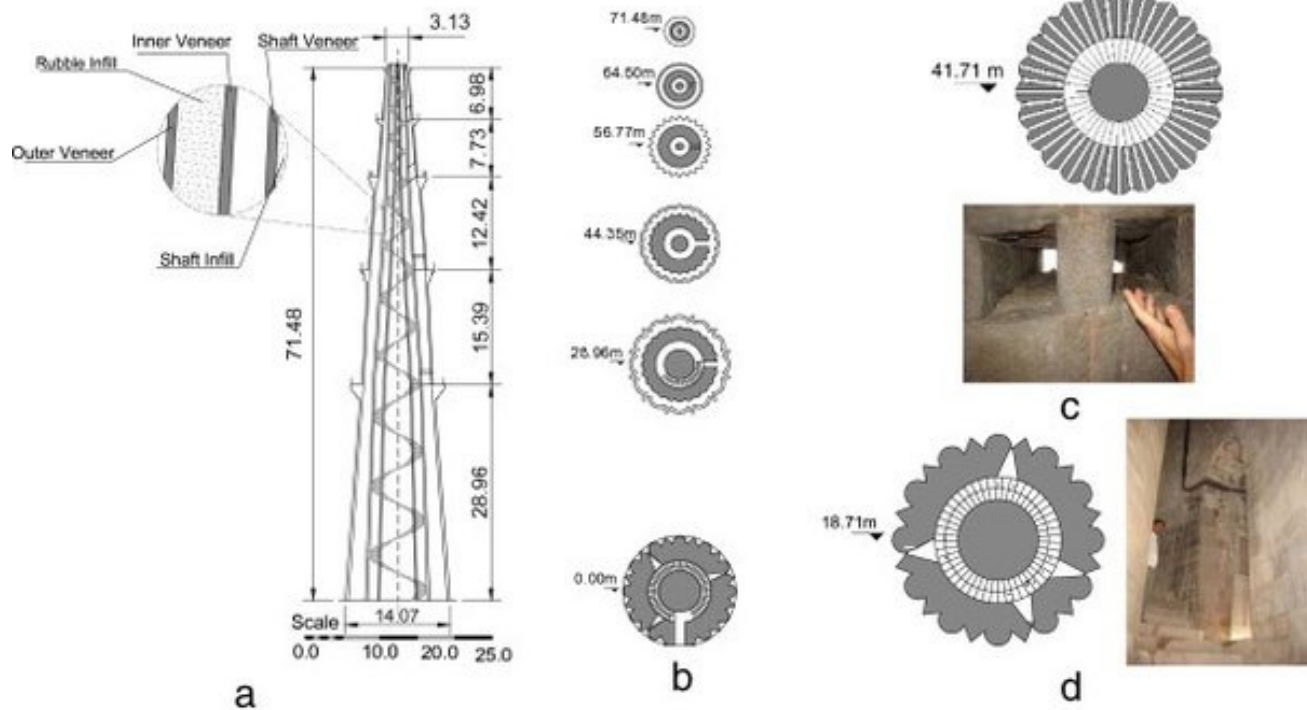
From the intricate carvings, can be noted an aura of the Afghanistan pattern, blended with local artistic conventions having garlands and lotus borders. Fortunately, renovations of the minaret throughout time have maintained the original charm of the building. **Each of the five different stories has a projected balcony that circles the Minar (backed by stone brackets).**

The structure of Qutub Minar is based on a polygon of 24 facets. The above structure is a formed of alternate angular and semicircular flutes. This is made on purpose to develop strength in such a tall structure for its time. Without this shape, it would have been very difficult to keep such a structure, still, with medieval technology and materials. It should also be noted that Qutub Minar was not made by one person at one time, instead, the whole structure was constructed in stories over several royal families and generations.

**Qutub Minar is a wonderful example of vertical, radical and rotational symmetry.**



## Surface Area Of Qutab Minar



([PDF] Seismic Vulnerability Assessment of Qutb Minar, India | Semantic Scholar (<https://images.app.goo.gl/LZaNHGYHn1B48Hr27>))

Qutab Minar as a shape can be visualized as a combination of frustums.

The slant height of then frustum = 73.23m

Radius of the top i.e.  $R = 1.35\text{m}$

Radius at the bottom is  $r = 7.15\text{m}$

Height of frustum = 73m

Lateral Surface Area =  $1955.50\text{m}^2$

Top Surface Area =  $5.72\text{ m}^2$

Total Surface Area = Lateral Surface Area + Top Surface Area =



$$1955.50 + 5.72 = 1961.22 \text{ m}^2$$

### Volume of Qutub Minar

Base radius 'R' = 7.15m

Radius of top 'r' = 1.35m

Height of Qutub Minar = 73m

volume of Qutub Minar =  $\pi h/3 (r_1^2 + r_2^2 + r_1 r_2)$

$$= 1/3 \times 3.14 ((7.15)^2 + (1.35)^2 + (7.15 \times 1.35))$$

$$= 4785.29 \text{ m}^3$$

### Iltutmish Tomb

Another structure present in Qutab Complex is Iltutmish Tomb. It is a tomb of Sultan Iltutmish. One of the beautiful structure and point of attraction in Qutab complex is a simple chamber, square in shape having dome shape cover on the top. This dome here also based on the squinch-arches, which serves to negotiate the difference in shapes as base is square plan and top is spherical.



The tomb has 3 entrances with fourth one closed, on the west direction. This entrance is closed to accommodate the 3 mihrabs' inside the structure. The interior of the tomb is highly ornamented with geometrical patterns, lattice work and arabesques. Whereas the exteriors of the building is almost plain. On the entrance and at some points verses of Quran in the form of Calligraphy can be seen. One can also see lotus flowers and bells, which are found carved in the sandstone. It is an exemplary of both Hindu and Islamic culture in terms of its designing and art, though dominance is of Islamic can be visualized.



This is the very first monument in India where the squinch as an architectural device is used to support to different shapes.

## Alai Darwaza

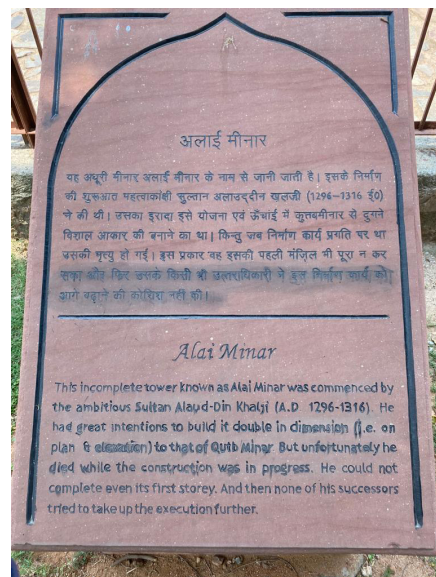
Alai Darwaza is also situated in the complex of Qutub Complex. It's an opening like a door covering area of 17.2 meter Square. It is buildup of red sand stone having fine work of lattice and arabesques. To give the Mughals' favorite red and white combo red stone is externally incised of marble bands and panels. It is an exceptional architecture of its own. It is the first building in India in which was completely based on Islamic architectural principal of construction.



The arch or mihrab on the North is semicircular while others are like pointed horse shoe shape.

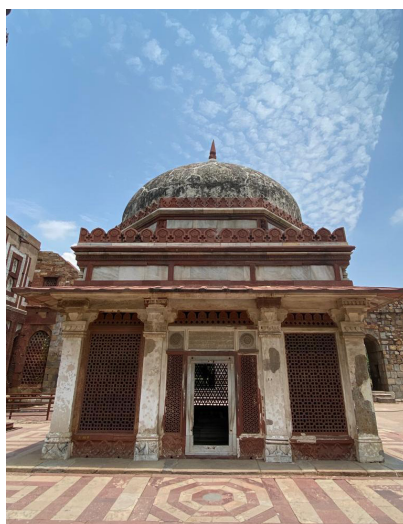
It is a true arch-based structure build using radiating voussoirs and lead into a central chamber.

## Alai Minar



Ali Minar is an incomplete structure of a tower intended by Sultan Alaud-Din Khalji. While its construction unfortunately he passed away and after him none of his successors took initiative to complete it. Ali Minar stands at 24.5 meters height.

## Imam Zamins Tomb



Imam Zamins Tomb is another mausoleum constructed in Qutab Complex. It has a simple structure of Lodi style.

Like other tombs it is also a sand stone structure with a dome standing on an octagonal drum and is constructed in the area of 7.3 meters. The grave is square in shape. Octagonal drum along with the square boundary is decorated with double rows of kanguras and marble panels above the chajjas.

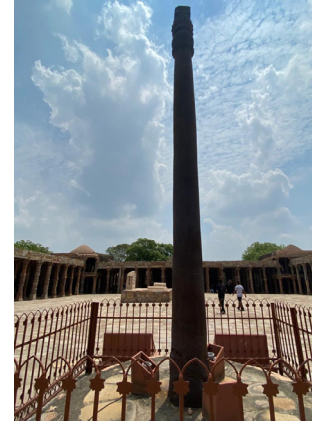
The structure is pillar based and standing on 12 square pilasters. The space between the pillars is covered with jalis of red stone except west and south. The jalis are ornamentally decorated with the various designs of geometrical shapes and presenting the example of tessellation with in them. This structure is also a combination of red and white stone.





## Iron Pillar

In the Qutab Complex there lies a pillar commonly known as Iron pillar. The pillar is of 7.21 meters i.e. 23 feet and 8 inches high with the diameter of 41 centimeters i.e. 16 inches weighing approximately 6 tonnes. It was built in the regime of Chandragupta II. It is known for its high resistance to corrosion.



## Designs and Patterns:

It is a combination of various types of patterns.

- **Jali patterns** -Jaali means net .Jaalis are carved on red stone or white marble .Jaalis are extensively used in Mughal Architecture for windows ,edges of platforms ,and terraces.

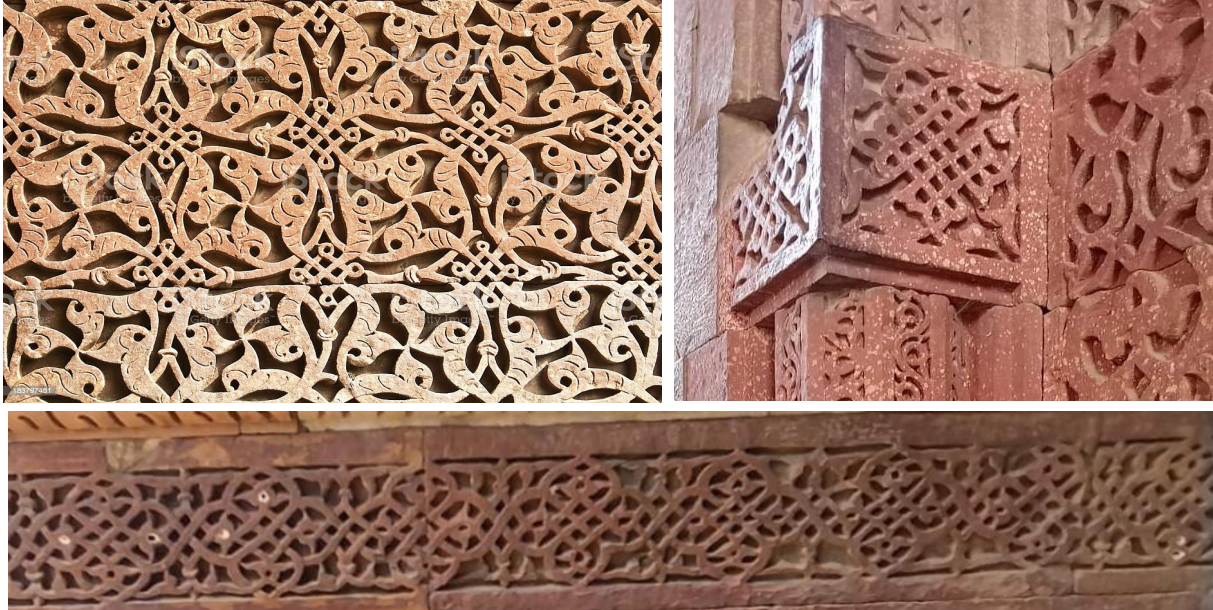


- **Geometrical patterns** -Another design pattern used in Mughal architecture is repeated geometric patterns .Even Jaalis have geometric patterns





- **Arabesque** -Arabesque is a pattern made by interlacing lines and curves .Arabesque is another major design used in Mughal period .It is the art form that Mughals carried with them.



- **Calligraphy Designs** -Calligraphy is another defining characteristic of Mughal architecture. The Qutub Minar has calligraphy designs running around the Minar. These are in the form of bands .This has the text from Qurans.



This sandstone structure measures **9.1 meters** along each side and is **8.41 meters** in height.





## Qutub minar and hexagram

HEXAGRAM- A Hexagram is a star-shaped figure formed by two intersecting star-shaped figures. The hexagram is the **symbol of the supreme unity of matter** and spirit within ourselves.





## TOMB OF SULTAN GHARI



**Location :** The tomb of Sultan Ghari is located on the outskirts of Vasant Kunj.

**History :** The first Islamic tomb built in India by Iltutmish in 1231 AD is Sultan Ghari. He built this tomb in the memory of his eldest son Nasiruddin Mahmud.

**Material:** The building of the tomb is made up of exotic Granite with a shiny gray base with very little and light brown lines on the surface. But the tomb of the Sultan Ghari is made up of red sandstones, marble and well burnt bricks.

## Mathematics and Architecture

This tomb looks like a small fortress from the outside with a colonnade creating an outer line. The four domed bastions and domes in each corner. In the middle of the courtyard is an octagonal Cave, which acts as the roof of the tomb on the ground. The stairs to reach the tomb are made of stones. Pictures of Yaksha, Crocodiles and lotus leaves etc can be seen on the walls of the tomb.

## THE ENTRANCE OF SULTAN GARHI TOMB:



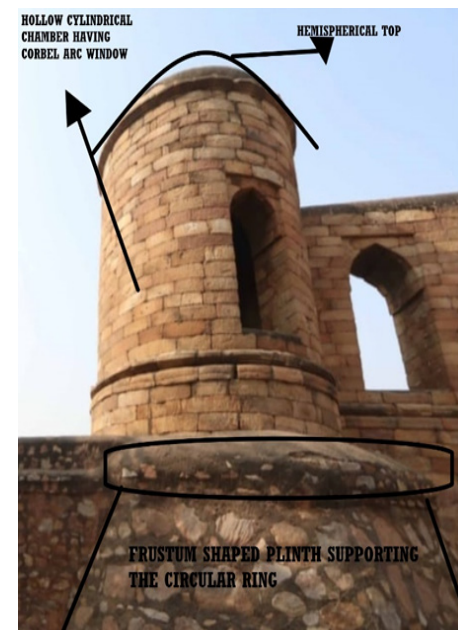
The entrance of the tomb is made purely from lavishing white marble. The Islamic inscription on the entrance gate exhibits the information about the person buried inside, the maker and the date of its construction.

The main door frame of the tomb is rectangular in shape which is fitted with the curve shape entrance. The

arche is pointed and reflects vertical symmetry in the entrance as well as building on both of its sides.

On each of its side there are 3 corbel arch windows and 1 Pyramidal tomb surmounted on a hollow Circular Bastions building which was further standing on a Frustum shaped base that shows the concept of congruency having line of symmetry along with the pointed arch of the main gate.

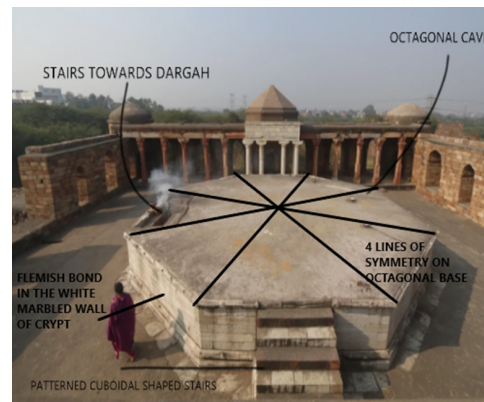
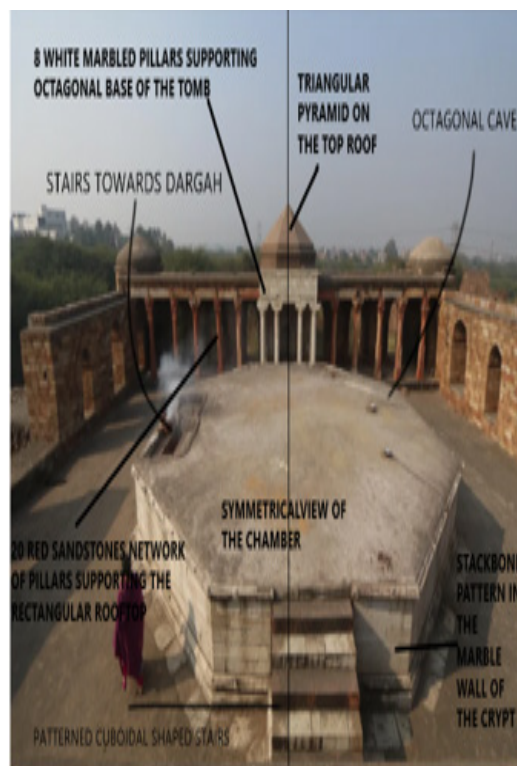
Inside this Big door frame there are 3 internal rectangular shaped door frames followed by one wooden door. The internal rectangular door frames depict how precisely they have used the concept of proportion for the construction of this iconic White marbled frames having beautiful Arabic inscription inscribed on it.



## THE OCTAGONAL CRYPT:

The octagonal crypt (8-sided polygon) is at a height of approx. 10 feet being supported on four columns that were raised with two pillars each to

maintain the beam. There is an underground chamber beneath the crypt. The roof of the chamber is made up of thick concrete lines. This octagonal crypt has eight sides and all the sides are of the same size. The octagonal base has four lines of symmetry that is just half the number of sides. Thus, it has rotational symmetry. From the lower rectangular shaped stairs, one can have a symmetrical view of the chamber from both of its sides. To reach this beautiful crypt, one has to climb around seven stairs built in a pattern of two different materials. The marble bricks in the crypt have a Flemish bond that is created by alternately laying headers and stretchers.



## CHAMBER VIEW :

From the front one can experience the amazing view of this magnificent monument having a triangular pyramid on the top of mihrab with octagonal base supported on a rectangular shaped roof standing on eight marble pillars. The symmetry





can be easily viewed inside the chamber having equal number of pillars and windows on both of its sides. The mihrab is constructed by using white marbles and red sand stones. The pillars and rectangular roof is made up with marble whereas the pyramid shaped dome is made up of red sand stones. The piece can be felt when one notices such a variety of shapes in the form of symmetry and design. The domed windows in the chamber are placed at equidistance having pointed arches which dictate the way light fills a space and have proper cross ventilation.

### ORNAMENTAL WALL :

The beautiful naturalistic style pattern in this wall has been made using basic mathematical concepts of curve, circle and oval. In this wall, the artisans have used mathematical shapes having some sign to preserve their sacred values of the culture like the circle that depicts the sun, the square depicting earth, the triangle depicting mountains and the spiral is for the movement. This ornamental wall is a kind of message to their descendants by means of non-verbal communication.



### WHITE MARBLED MIHRAB :

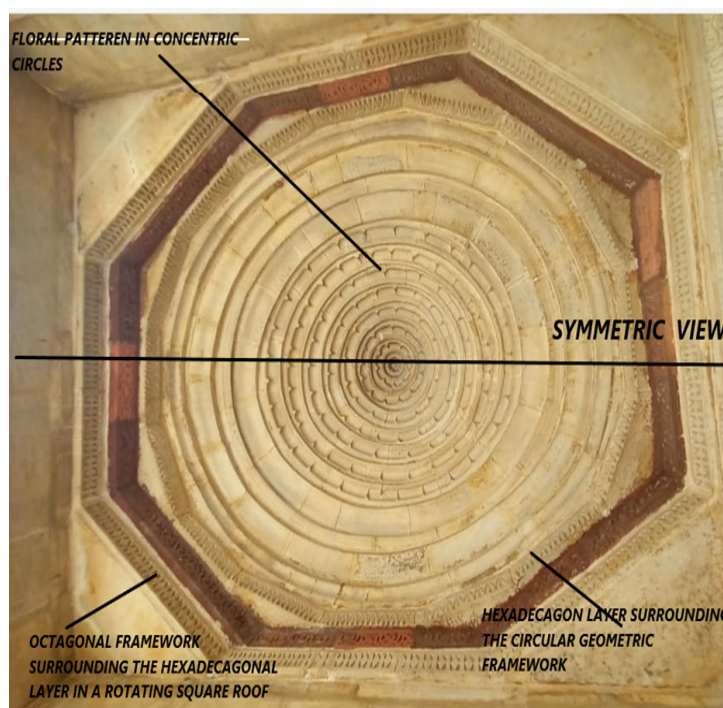
To reach this majestic mihrab, one must walk around the boundary of the courtyard. The walls of this beautiful mihrab have quranic scriptures elaborately carved on it. The mihrab is a semi circular niche in the wall of a mosque that indicates the direction of Mecca which Muslims face while praying. The outermost rectangular door frame contains cursive verses from the Qur'an and a floral design having circles and triangles.



The frame around the niche is decorated with arabesque design in the outer layer. The ghoonghat wali mihrab gate has two identical octa hexagonal pillars standing on square base and two hemi spherical shaped supports surmounted on each other. The architecture involved in the construction of this splendid mihrab majorly uses the mathematical shapes both 2 dimensional and 3 dimensional and the symmetrical patterns. There are two symmetrical exits from both ways lying at the same distance from the entrance of the mihrab.

### DOME OF PRAYER CHAMBER :

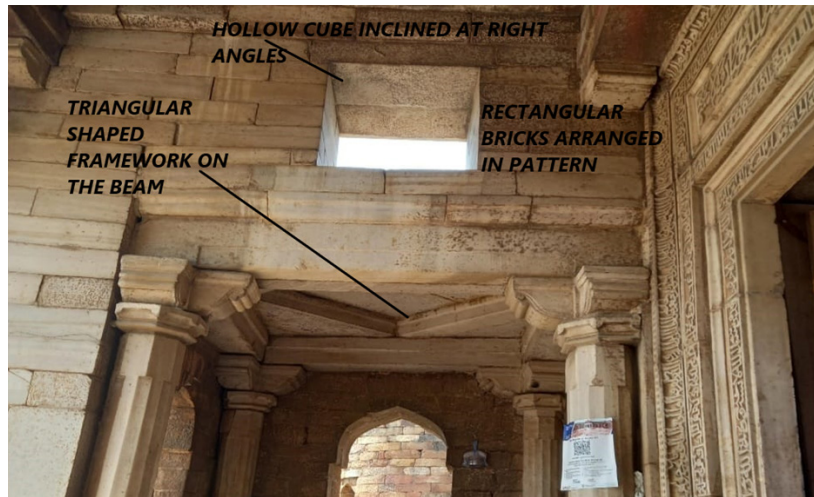
As soon as one raises one's eye upwards, one can see a very magnificent roof which is in a round circular shape showing the concentric circles having a floral design pattern. Here the circles are fitted in six sided regular polygon which is further fitted in octagon. This design used here is not for architectural beauty rather its an intelligent use design to fix the hemisphere on the four sided structure without



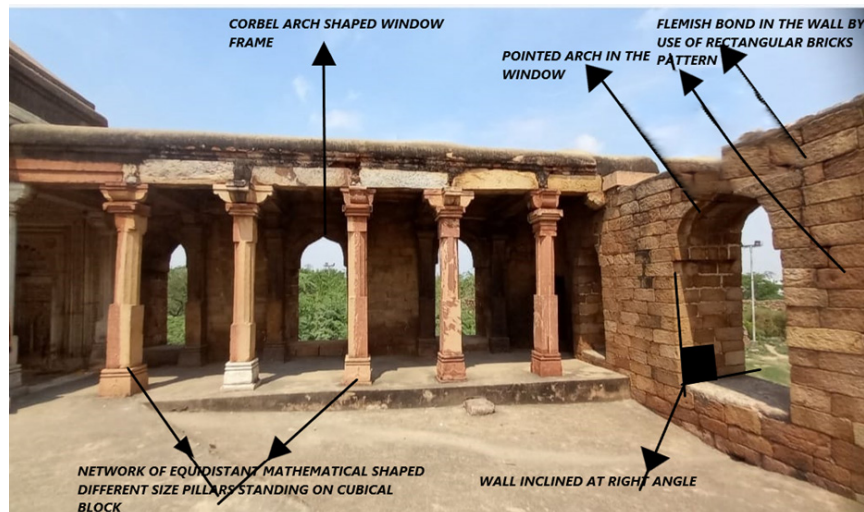
any gaps and to strengthen the building. Patterns in painting sometimes also incorporate storytelling by incorporating design elements with some symbolic meaning. Inside this concentric circle ceiling, as the radius increases, so does the circle. The brick pattern can be seen in the circular ring as a geometric framework surrounded by a layer of hexa-decagon (16 sided figure) which is further surrounded by a layer of octagonal design having a triangular pattern in it. Here the concept of mathematics can be easily visualized as the number of sides of the polygon increases the circle will be formed having no side.



## INTERIOR VIEW OF MIHRAB :



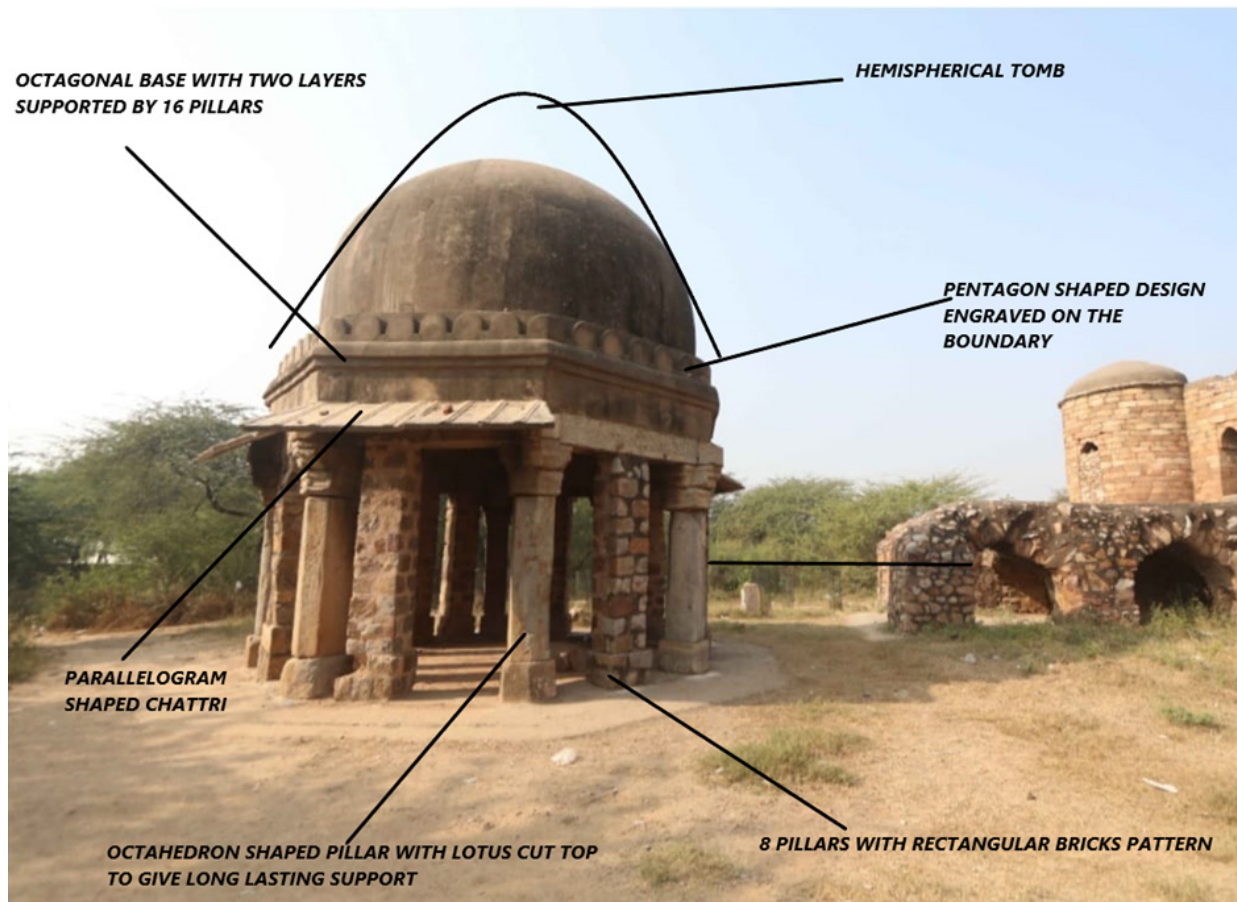
The inside view of mihrab has one hollow cubical opening having a right angle on all its vertices. It is purposely done to avoid rain and sunlight entering through it. The walls of the mihrab have a stack bond of bricks that are directly lying on top of one another running vertically down as well as a stretcher bond in which bricks are arranged on each course cantered above and below by half a brick. The beam of the roof is triangular shaped and the windows in the interior part have a pointed arc. The pillars in the temple have square cut base and topped up by lotus cut shaped columns so as to give maximum support to the roof.



There is a network of equidistant mathematical pillars in the western colonnade of the prayer chamber. Here all the pillars are of different sizes,

the base of all the pillars are cubical blocks having cuboidal blocks of different dimensions surmounted by a lotus cut column on each of them. There are a total of twelve pillars on which the roof of mihrab stands.

## THE TOMB ADJOINING THE SULTAN GHARI :



On level ground fifty feet to the south of sultan ghari's tomb is situated this tomb. It is a gemstone chhatra having a hemispherical tomb surmounted by an octagonal base having pentagonal design on all over its boundary resting on eight monolithic columns. There is a parallelogram shaped chhatra over the level of pent to protect from rain. The monolithic columns have two different shaped pillars arranged in an alternative pattern.

The ceiling inside the tomb consists of a concentric circle with the same centre with different radius. The symmetric repetition of blocks can be prominently observed in the circular rings lying inside the rotating square roof.



## Tomb of Sikander Lodhi



**Location :** The Lodhi Tomb is in Delhi's Lodhi Garden. The monument is situated 100 meters away from the Bara Gumbad and the area in which it is situated was formerly a village called Khairpur. The location of the tomb is [28°35'46.5324"N 77°13'17.6340"E](#).

**History:** Tomb of Sikander Lodhi erected by his son, name Ibrahim Lodhi in the year 1517. Sikander Lodhi is the second ruler of the Lodhi dynasty. He was the Sultan of Delhi between 1489-1517 CE (approx. 75 years). The structure was built between 1517-18.

**Material:** The red sandstone material is mainly used to build the tomb.



## Mathematics and Architecture:

Sikander Lodhi tomb is set in a garden surrounded by an elaborate enclosure about 76 meters square, with walls 3.5 meters high. The two chhatris (pavilions) on the square platform in front have remains of blue tiles. Inside the enclosure, the middle part of the western wall has been built so as to function as a wall mosque, with the qibla (direction of the prayer) indicated through arches and a paved area in front, in the center of the enclosure is the octagonal tomb. Its interior is decorated with extensive and fairly well preserved tile work and a painted and incised plaster ceiling.

The most fascinating part of the tomb is its octagonal base on which the structure of the monument is placed. It is a combination of Mughal and Sayyid architectural design having eight sides, tall semi-circles and long intense barabdas.



Interior look of the tomb

The grave is encircled and perforated by three curves or arches along with slanting structures occupying the angles. The two-story structure from outside is a single chamber with high ceiling of dome type which is based on again an octagonal structure to support the construction. The dome is hemispherical and has sixteen-sided drum extends. This structure stands on the 12 meters tall strong walls to which dome adds the height of 14 meters and the total height of the building from ground level comes to 29 meters. All around there are 24 openings in the whole building.

All the 16-sided drums are exactly same revealing the congruency among each other, The structure is another example of symmetry, congruency, and tessellation.

Arche A and Arche B are beautiful examples of use of similarity. This principle of similarity can be seen in various openings around the grave.

Sixteen sided drum at the top of octagonal base



Each opening has 3 compartments. The central compartment is proportionate to the two besides it. There is a vertical symmetry in each compartment, on every side of the octagonal face and in the complete tomb.

Its plinth is decorated with an ogee arch opening set into rectangular frames. Typically, Indian carved corbels are often used in conjunction with the arch. Each face of the drum is described by an ogee arched opening set into rectangular frames.

Ogee arch in a rectangular frame

Vertical line of symmetry



Every octagonal face have three openings

The outer boundaries of the wall also have an ogee arched opening set into rectangular frames. Many foreign languages are inscribed in the tomb.



## HUMAYUN TOMB



**LOCATION:** The tomb of Humayun is located in Southern part of Delhi on Mathura Road, across Nizamuddin Dargah.

**History:** The first of the large dynasty mausoleums that can be associated with Mughal dynasty and architecture is Humayun's tomb in Delhi. It is an illustration of Charbagh, in which pools are connected by canals.

It was constructed in 1564 A.D. by Haji Begum, wife of the emperor Humayun. It was built after 8 years of the death of the said emperor in Delhi next to the city founded by him. A Persian architect Mirak Mirza Ghiyas was hired for designing of the structure and is identical to Taj Mahal.

Another name for Humayun's tomb is "DORMITORY OF THE MUGHALS", where the remains of our Ancient Mughal ancestors are interred in cells.

**Material:** The mausoleum is placed in a spacious, square park-like enclosure, providing seclusion, and securing an appropriate setting. Rubble Core stone is used in the construction. Red sandstone with white marble combination like other Mughal buildings is used in the structure. The pavement is made of red stone. The dome is totally covered with marble.

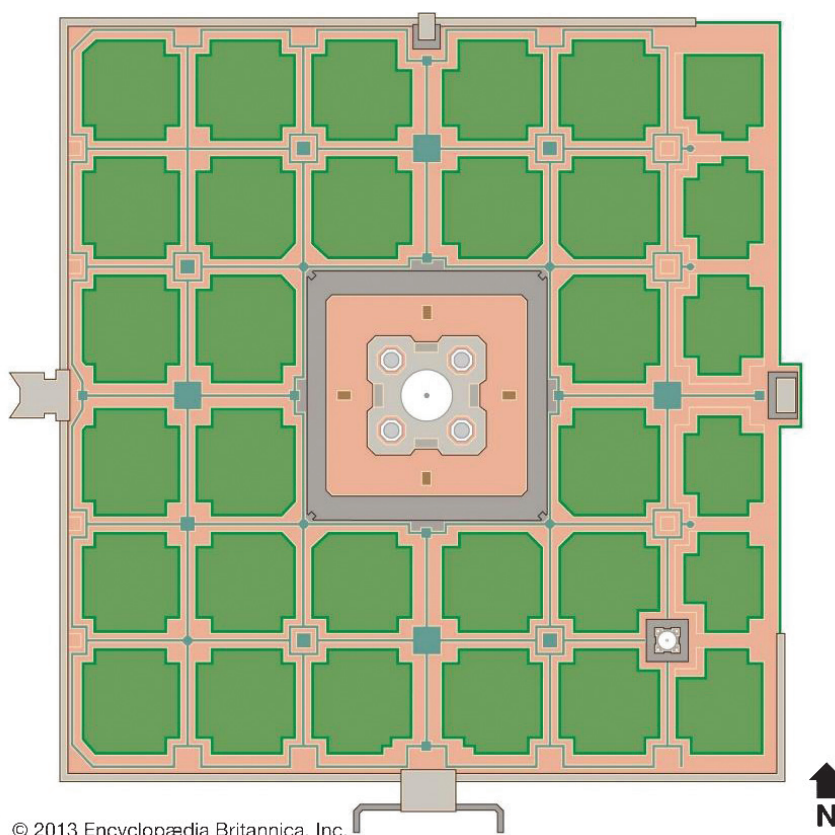
## Mathematics and ARCHITECTURE:

Humayun Tomb is a historical as well as mathematical masterpiece standing strong from last 450 years. The total area covered by the monument is 10-hectare that is 25-acre and is 140 feet high that is equivalent to 14 floor building.



Mausoleum is located at the center of a vast garden. Design of the layout of the space is based on the Char Bagh (a four quadrant garden), a “paradise garden” inspired by the description of paradise in Quran. The tomb is at the center of the garden with the 21 feet high plinth. It is a double layered dome. The tomb structure, which is a square in plan with 156’ sides. Surrounding Park of the sarcophagus is divided into 4 big square parks by the pathways and water channels. Each of these 4 squares is further divided in 3 by 3 thus the whole area is divided into 36 smaller squares in all. The structure of tomb is standing on the four central squares. Out of these 17 structures are in front of Humayun tomb

## Humayun's Tomb



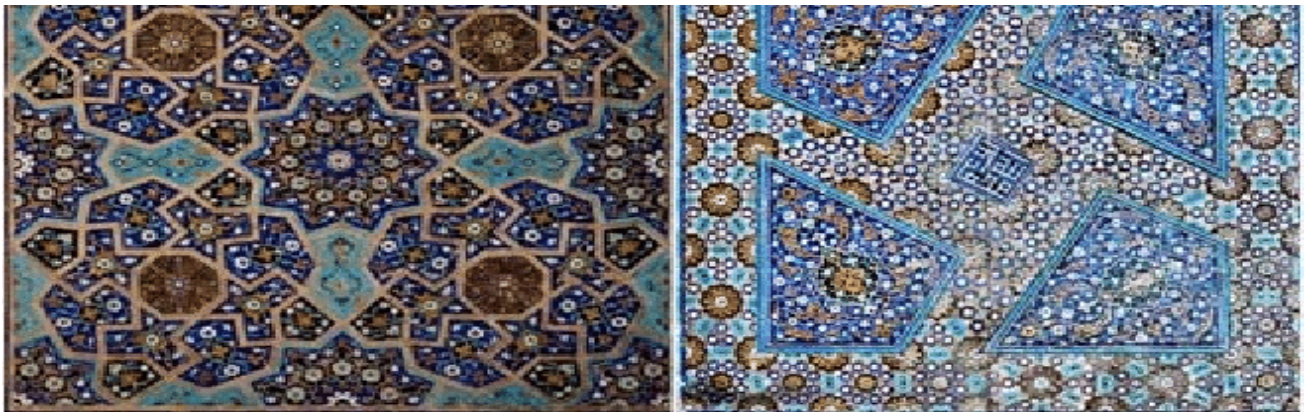
The main tomb is designed on square base with 'a fold plan' having dome shape chamber with double height. It has 8 two storied vaulted chambers radiate from central part. All the chambers in each story are internally connected in diagonal and straight passage. At ground level there are 124 vaulted chambers which are symmetrical and well-proportioned. The pedestal, which is made of debris, has more than a hundred tombstones inside and is surrounded by 56 chambers. Each room is octagonal in plan and they are connected to one another with diagonal passages. 139 feet and run 6 meters (20 feet) high. The end in a crescent, achieving a height of 47 meters (154 feet), and the plinth is 91 meters (299 feet) broad.

The garden is laid out in the arrangement of square and rectangular compartments with flowered parterres and flagged paths and pavements which are carefully designed and proportioned to align with integral part of the structure. The lines and spaces leading up to and harmonizing with those of the central structure.





All four sides are alike in elevation, with each face consisting of a central rectangular fronton containing an arched recess and flanked by embowed wings each relieved by a similar but smaller arched alcove. Lattice screen/ jali, eaves(edges of roof overhang)/chajja , vaulted terrace best example of math's combination . Height of Humayun tomb is 8 meter & spread(area) 12.00 meter square





## LOTUS TEMPLE



**LOCATION :** Lotus temple road, Near kalkaji , New Delhi. Concrete was used to cut the frame, and a precast concrete ribbed roof with 27 white marble-covered petals was added.

**History :** Lotus temple also known as Bahai mandir is a house of worship. It was designed by Iranian architect Architect Fairborz Sahba's and its construction started in 1978 and was completed in 1986. It is a symbol of peace purity and love and just because of that it was structured in shape of Lotus. It also transmits the idea of immortality. It is one of the beautiful creations of mankind though it has a complex structure of various shapes and designs. Thus, Lotus Temple derives its name from its design.



The construction of Lotus temple is inspired from the animated show “**Legend of Korra’s Earth Kingdom**” city of Zaofu. Zaofu is a city of metal benders. The city closes itself up via metal bending at night, into the closed lotus form, much like the Lotus Temple.

**Material :** The white edifice is made of white marble and is surrounded by 9 pools having border of red sandstone. The main temple complex is having 27 petals of white marble with the central part covered with shade.



<https://i.pinimg.com/originals/04/ba/98/04ba986bd22145e0e5cd4d78b46e52a4.jpg>

## Mathematics and architecture:

The amazing structure of Lotus Temple is standing on an elevated plinth in an area of 26-acre i.e 10.5 hectare. The diameter is 70 meters i.e. 230ft. It is surrounded by gardens and 9 pools with the walkway of red sand stone. The height of the building is more than 130 feet about 40 meters and is comprised of 27 independent petals shape of marble. These petals can be grouped into the group of three which form nine sides of the structure. From each side there is an entrance to the central space of the temple.



### ORGANIZING PRINCIPLE - RADIAL

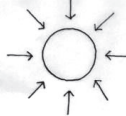
A RADIAL ORGANIZATION OF SPACE COMBINES ELEMENTS OF BOTH CENTRALIZED AND LINEAR ORGANIZATIONS. IT CONSISTS OF A DOMINANT CENTRAL SPACE FROM WHICH A NUMBER OF LINEAR ORGANIZATIONS EXTEND IN A RADIAL MANNER. IT IS AN EXTROVERTED PLAN THAT REACHES OUT TO ITS CONTEXT. WITH ITS LINEAR ARMS, IT CAN EXTEND AND ATTACH ITSELF TO SPECIFIC ELEMENTS OR FEATURES OF ITS SITE.



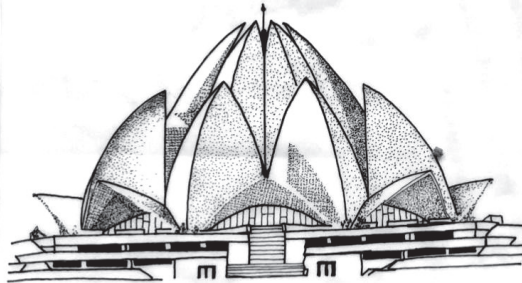
CENTRAL SPACE



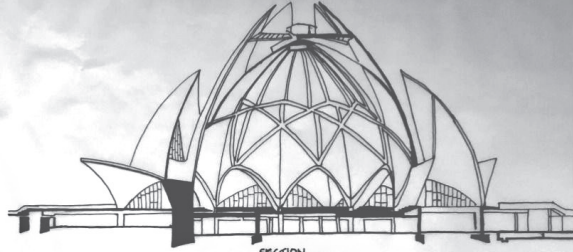
LINEAR ARMS



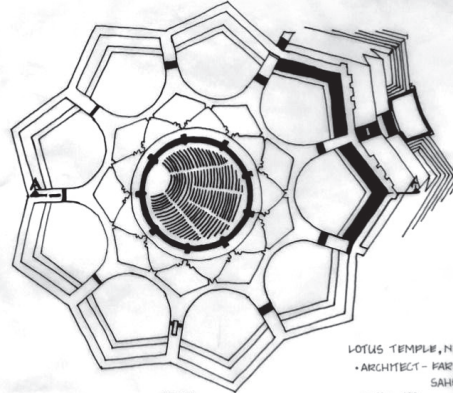
THE CENTRAL SPACE OF RADIAL ORGANIZATION IS GENERALLY REGULAR FORM. THE LINEAR ARMS, FOR WHICH CENTRAL SPACE IS THE HUB, MAYBE SIMILAR TO ONE ANOTHER IN FORM AND LENGTH.



ELEVATION



SECTION



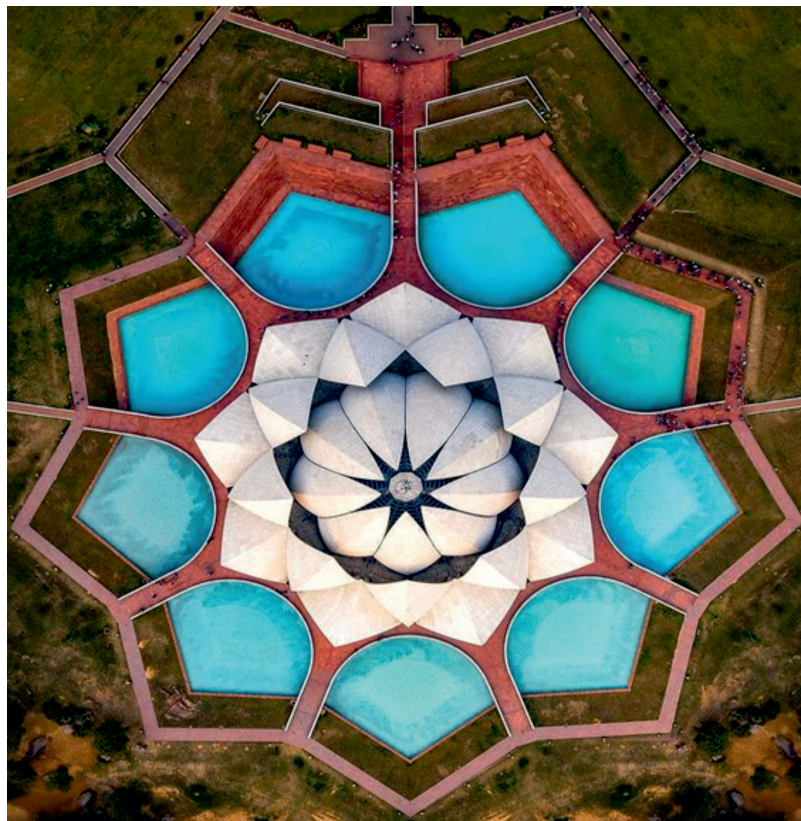
PLAN

LOTUS TEMPLE, NEW DELHI  
• ARCHITECT - FARIBORZ SAHBA  
• YEAR - 1986

### ORGANIZING PRINCIPLE - RADIAL

STAFF SIGN:	SHEET NO: 01	SCHOOL OF ARCHITECTURE
DATE:	NAME: SHUBHA CHUGHANAR	
SEM: IV	USN: 1700100000000000	

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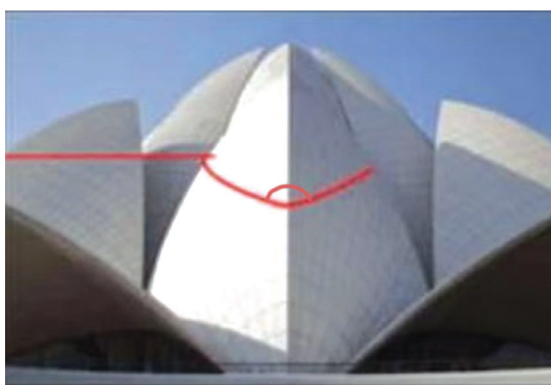
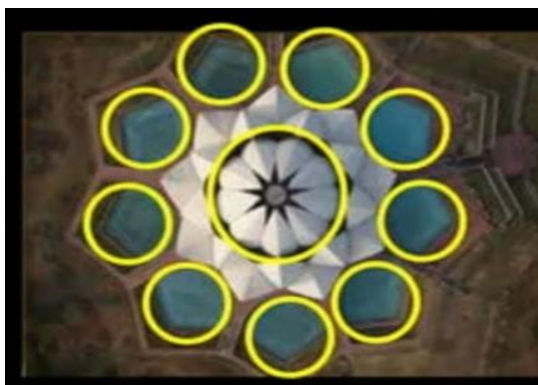


<https://i.pinimg.com/1200x/a2/e4/6c/a2e46c53d0e9a2f613a8e504e129b6e2.jpg>

This is the specialty of this temple erection that it has 9 gates, 9 corners and each corner with a pool. The concept of 9 is based on Baha I belief in the properties of 9 and like any other Baha I mashriq. It is believed that 9 symbolizes unity, oneness and inclusion of all.

## SPATIAL AND GEOMETRIC ASPECT

From the top view we can visualize three concentric rings having a group of nine petals in each circle. The petals in the outer circle is facing outward like a canopy on each of nine entrances. The middle ring petals are facing inward covering the outer hall whereas the innermost ring of petals is also facing inward and walling the central hall of prayer. The capacity of this hall as stated by authority is 2500 at a time. The top structure of the hall is made of glass and steel to let natural daylight in the prayer hall. The innermost dome is almost spherical in shape as the petals are adjusted in ring.



Lotus Temple, which was designed to emulate the beauty and symmetry of the lotus flower also is an exemplary of arrangements in term of multiples of nine. It is not only biomimicry in contemporary design but also a prominent example of mathematical symmetry.

On drawing a line on front of the building the **vertical symmetry** is evident. Also, all the nine sides are identical thus it is a wonderful example of **rotational symmetry** which is very evident from the top view of the structure.

Let us find the angle of rotation:



The total angle is **360°** where as it is divided into 10 symmetrical parts thus **360° / 9 = 40°**. Thus, the angle of rotation is **40°**. The spatial organization of the main structure is centrally organized, moving from center to outwards. In plane it can be visualized as composition of circles and segments of circle as shown in the picture.

## SCALE AND PROPOTION

### Scale

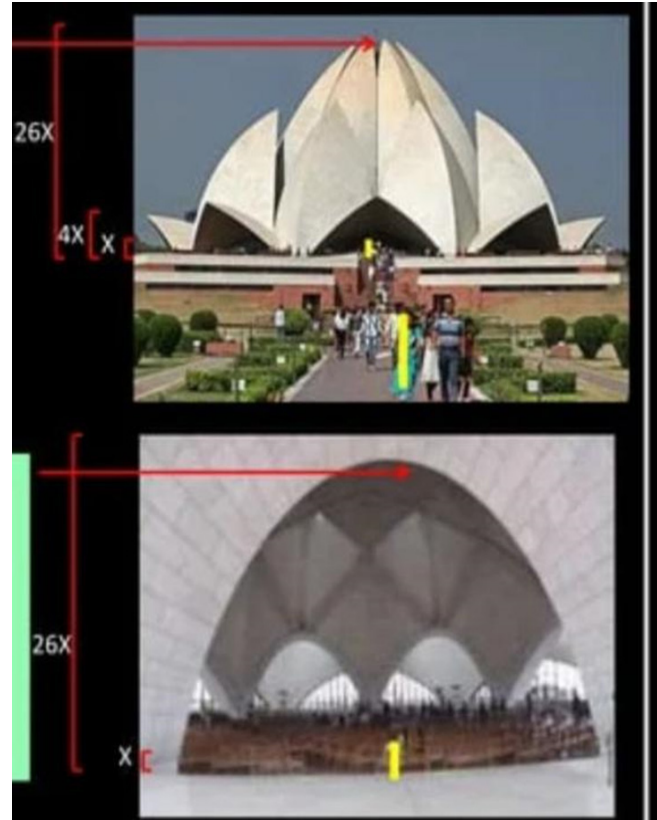
Scale alludes to the size of something compared to a reference standard or two sizes of something else. It's external structure consists of 27 giant marble petals reaching to a height of up to 40 m.

### Proportion

Proportion refers to the proper or harmonious relations of one part of another or to the whole. On exploring proportion in the structure of Lotus temple we can see that the entry gate in the main hall is human scale with almost 4 m of height. On the contrary the main prayer hall is almost 40 meters high. This reflects the proportionality of 1:10 between the entry gate and the ceiling of the main prayer hall.

**The surface is all inclined to 45-degree angle from each other.**

★ ★ ★



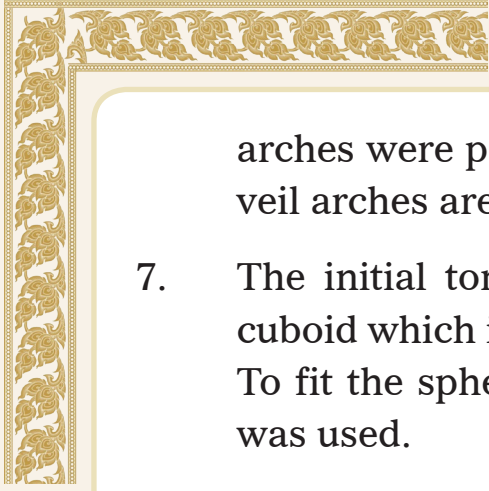


# 4

## Findings of the study

The major findings of the study are as follows:

1. All the monuments are unique and having a hidden mythology and history behind it. On envisaging from mathematical aspect all gives a consistent picture of various aspects of mathematics and culture deeply intertwined in practical terms.
2. These monuments are live examples of applied mathematics and genius spatial understanding.
3. Reflecting on the structures of monuments it was evident that the use of shapes in structure of tomb changed from pyramid to spherical tomb with the use of squinches, concentric circles and regular polygons namely hexagons, octagons and decagon.
4. The patterns used for designing in initially were motifs of flowers, leaf and animal faces which was used in Hindu culture. But with invasion of Mughals this designing and patterns with the passage of time shifted to more of geometrical shapes and patterns, calligraphy, and arabesque.
5. Geometric patterns in Mughal buildings were based on more of Islamic geometry which is based on polygons and restructuring of polygons or combinations of various regular shapes. The shapes were explored and tessellated to create new patterns. Again, the dominance was of hexagons, octagons and various types of stars.
6. Initially monuments especially tombs were pillar based and true



arches were popular. Later false archs came into existence and the veil arches are common in Mughal buildings.

7. The initial tomb of Sarai Sha ji has pyramid structure fitted on cuboid which in Humayun tomb, Lodi tomb changed into spherical. To fit the sphere on cuboid and to fill the gaps squinch technique was used.
8. Each monument has a religious connection as well as mathematical. The structure is a lively example of deep connection of mathematics embedded in culture. Like Humayun tomb is based on the char bagh, paradise garden described in Quran. Also the whole is divided in major 4 squares which are further divided into squares of 3 by 3. In all the area can be interpreted in terms of 36 squares. Similarly Lotas Temple is based on the concept of 9 as 9 is considered auspicious in Bahai Community.

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# 5

## Conclusion & Discussion

Exploring monuments has been an incredible learning experience as these are the miraculous mathematical structures and the exemplary intertwining of mathematics in culture. Mathematics, besides geometrical patterns in decoration is present in combination of various parts of structures which make them stand strong. Use of symmetry and congruence, mensuration with numbers especially in Humayun tomb and Lotus temple make them exceptional buildings as they are structured based on the perfect combinations of number based structures and geometrical concepts. Swetz (2012) stated that inclusion of history in the teaching-learning process of Mathematics helps to humanize mathematics and provide relevance to mathematical curriculum. In this research too the mathematical concepts found their relevance in the structures of various monuments and are lively examples of humanization of mathematics. The designs and layouts used in the monuments are deeply rooted in a particular culture which is also stated in wikipedia on Islamic geometric Decoration. The document states that Islamic geometric patterns were related to the spiritual realm which were used as instruments to purify mind and soul. Similarly the number 9 is treated as a pious number in Bhai community and the structure of their religious place is based on the concept of 9. Same can be visualized in Humayun Tomb which is based on the concept of Charbagh inscribed in the script of Quran.

The monuments not only describe the social environment of that time but also it reflects about the civilization and development of mankind.

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## GRADE WISE MATHEMATICAL CONCEPT AND MONUMENT

SL. No.	Mathematical Content	Class	Monument
1	Symmetry	3 to 7	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Lotus Temple
2	Ratio & Proportion	6 & 7	Tomb of Sarai Shanji,
3	Visualizing Solid Shapes	6 to 8	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, Qutab Minar, Humayun Tomb,
4	Basic Geometrical Shapes	6 to 8	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, Qutab Minar, Humayun Tomb,
5	Congruency	7 & 10	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, Qutab Minar, Humayun Tomb,
6	Coordinate Geometry	8 on-wards	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, Qutab Minar, Humayun Tomb,
7	Surface Area & Volumes (Combination of solids)	8 to 10	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, , Qutab Minar, Humayun Tomb,
8	Trigonometry	10	Qutub Minar
9	Mensuration	6 to 10	Ugrasen Ki baoli, Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, , Qutab Minar, Humayun Tomb,
10	Pattern	3 to 10	Ugrasen Ki baoli; Tomb of Sikhandar Lodhi, Rai Pithora Fort, Tomb of Sultan Ghari Lotus Temple, Tomb of Sarai Shanji, Qutab Minar, Humayun Tomb,

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