

BUILDING SCIENCE OF INDIAN TEMPLE ARCHITECTURE

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Abstract

Every style of building construction reflects a distinctive principle that represents a particular culture and era. In this context, the Indian Hindu temples are not only places of worship but they are also cradles of knowledge, art, architecture and culture. The practices and traditions of temples exist not only in history but also in present time, which greatly influence the socio-cultural life of its people and gives continuity to traditional Indian values. The evolution of Indian temple architecture is marked by a strict adherence to the ancient models that has continued over many centuries.

This paper presents the philosophical and practical aspects that govern the construction of a Hindu temple building and how they influenced the form of the Hindu temple. The various stages, construction techniques and processes involved in temple construction since ancient times have been studied not only through archival research but also through a comparative study. Dimensional studies have also been undertaken with respect to simple indexes of both the northern and the southern styles of Hindu temple architecture and are discussed in this paper.

1. INTRODUCTION

One of the most significant highlights of Indian architecture has been the evolution of the Hindu temple architecture. The Hindu temple construction during the medieval period (6th-13th centuries) took place on a magnificent scale comparable to the building of churches and cathedrals in the medieval Europe. A large variety of Hindu temples was constructed throughout India with distinction in scale, techniques of building and particularly the deities that were worshipped, which were the result of the differences in political, cultural, climatic, geographical and prosperity between the towns and villages.

Thus, distinctive architectural styles of Hindu temples developed which have been classified into three different orders; the *Nagara* or 'northern' style, the *Dravidian* or 'southern' style, and the *Vesara* or hybrid style which is seen in the Deccan between the other two. There are also other distinct styles in peripheral areas such as Bengal, Kerala and the Himalayan valleys.

The study focuses on the *Nagara* or the northern style, and the *Dravidian* or the southern style of Hindu temple architecture built in stone. It looks into aspects of their origin and development, the philosophy that created them and the way in which this philosophy can be interpreted for better understanding of the structure itself and the time and society that created them. The dimensional study of the temples was restricted to few examples from the north and the south temples due to the limited availability of the required information and drawings.

2. THE HINDU TEMPLE

The Hindu temples commonly known as *Mandir* in Hindi and derived from the Sanskrit word *Mandira*, are identified by several names in different parts of India. The architecture of temples varies across India; the basic elements of the temple are the same, but the form and scale varied. The following section describes the elements of the temple.

2.1 Elements of Hindu temple

During the late half of the 7th century, the Hindu temple structures of India began to acquire a definite form. Similar to terminology used to distinguish the basic components of a Gothic Church (for example nave, aisles, chancel, spire, etc), the common elements of a Hindu temple which are known in their original Sanskrit words are described next, see also (Figures 1 and 2)

The sanctuary as whole is known as the *Vimana* and consists of two parts. The upper part of the *Vimana* is called as the *Sikhara* and the lower portion inside the *Vimana* is called as the *Garbhagriha* (cella or inner chamber).

Also: (i) '**Sikhara**' meaning the tower or the spire. It is the pyramidal or tapering portion of the temple which represents the mythological '*Meru*' or the highest mountain peak. The shape and the size of the tower vary from region to region. (ii) '**Garbhagriha**' meaning the womb chamber. It is nucleus and the innermost chamber of the temple where the image or idol of the deity is placed. The chamber is mostly square in plan and is entered by a doorway on its eastern side. The visitors are not allowed inside the *garbhagriha* in most of the temples, only the priests perform the rituals and worship. (iii) '**Pradakshina patha**' meaning the ambulatory passageway for circumambulation. It consists of enclosed corridor carried around the outside of *garbhagriha*. The devotees walk around the deity in clockwise direction as a worship ritual and symbol of respect to the temple god or goddess. (iv) '**Mandapa**' is the pillared hall in front of the *garbhagriha*, for the assembly of the devotees. It is used by the devotees to sit, pray, chant, meditate and watch the priests performing the rituals. It is also known as '*Natamandira*' meaning temple hall of dancing, where in olden days ritual of music and dance was performed. In some of the earlier temples the *mandapa* was an isolated and separate structure from the sanctuary. (v) '**Antarala**' meaning the vestibule or the intermediate chamber. It unites the main sanctuary and the pillared hall of the temple. (vi) '**Ardhamandapa**' meaning the front porch or the main entrance of the temple leading to the *mandapa*.

Some other essential elements found in the Hindu temples are: (vii) '**Gopurams**' meaning the monumental and ornate tower at the entrance of the temple complex, specially found in south India. (viii) '**Pitha**', the plinth or the platform of the temple. (ix) '**Toranas**' the typical gateway of the temple mostly found in north Indian temple and (x) '**Amalaka**' the fluted disc like stone placed at the apex of the *sikhara*.

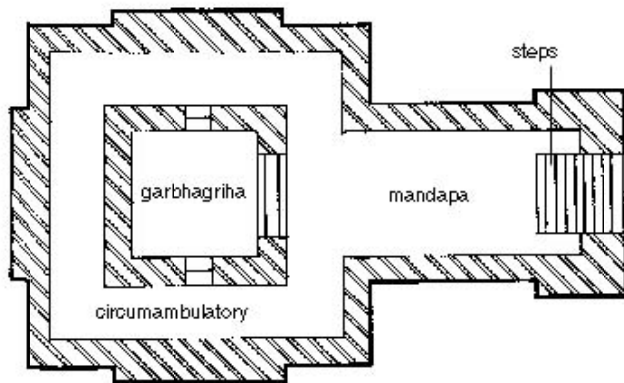


Figure 1: The typical plan illustrating various elements of Hindu Temple

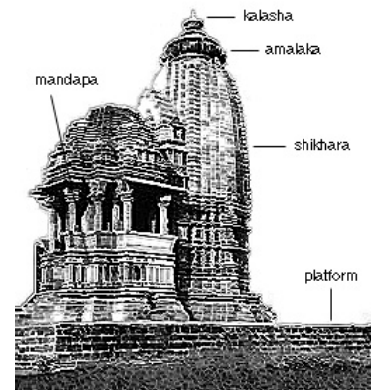


Figure 2: The typical elevation illustrating various elements of Hindu Temple

3. THE GEOMETRY OF HINDU TEMPLE

The Hindu architecture, religious or vernacular, in the ancient times was based on the geometry of the *Vastupurashamandala*. In Hindu philosophy, the form of the *purasha* (human) body was made to suit the abstract idea of the square, as the supreme geometric form (Grover, 1988), see Figure 3. The basic form of the *Vastupurashamandala* is the square which is the important and ideal geometric form in Hindu philosophy, which represents the earth. Similarly, the circle represents the universe and is considered as the perfect shape, without any beginning and end, suggesting timelessness and infinity, a typically heavenly feature.

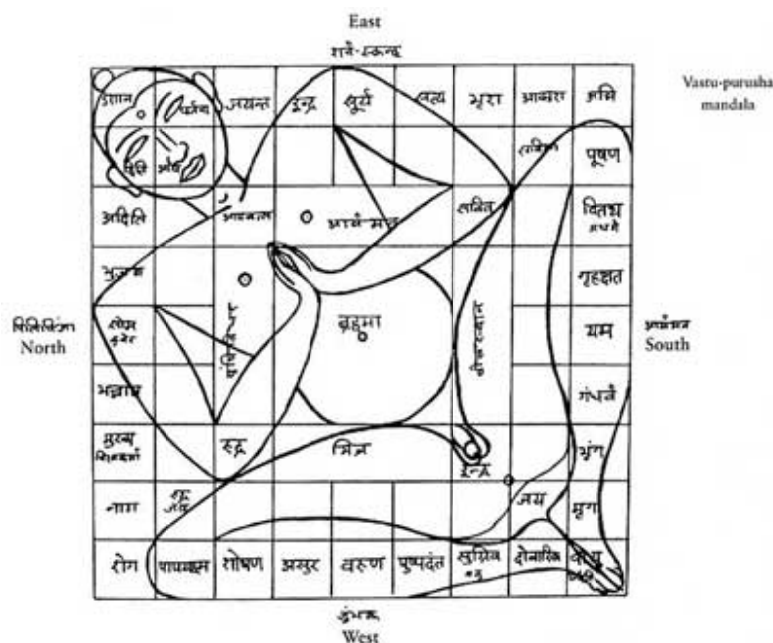


Figure 3: Vastupurashamandala

The *mandala* is actually a square subdivided into smaller squares in the form of a grid with each square unit clearly marking the areas of respective gods. The most commonly used *mandala* is the square divided into 64 and 81 squares. The *Vastupurashamandala*, having all the geometrical, astronomical and human properties was the basis of the ground floor plan for all Hindu temples. The basic shape acquired by the temple plan is the outer most ring of square of the *mandala* forms the thickness of walls of main shrine. The central 4 squares acquire the place of the main deity and the inner ring of 12 squares form the walls of the *garbhagriha* and the next 16 to 28 forms the *pradkshina patha*. These simple divisions of square with many permutations and combinations became the base for the complex structures of the temple.

4. THE STRUCTURAL SYSTEM OF THE HINDU TEMPLES

The basic construction technique used in the Hindu temple was the trabeated system or the post and lintel method which was extended by the use of corbelling techniques. This method was originally used for wooden construction in India and was later adopted for the stone structures as well.

4.1 Trabeated System

In the trabeated system only the horizontal and the vertical members are used and the stability is achieved by the massive arrangements of vertical elements such as pillars and pilasters together and heavy cross beams and lintels see Figure 4. The use of the spanning system to enclose the interior spaces was the most typical feature of this system. The roofing system consists of horizontally laid slabs of stone spanning from one supporting beam or wall to the other.



Figure 4: Trabeated system and the internal ceilings of the Hindu temple

4.2 Corbelling System

In the corbelling system the stones or the bricks in each horizontal course are projected out to bridge the gap between the two walls to diminish until it can be closed with a single piece of stone or brick see Figure 5. The corbelling system was used to create the interiors of the temple and the stone shells of the super structure that rise above the sanctuary.

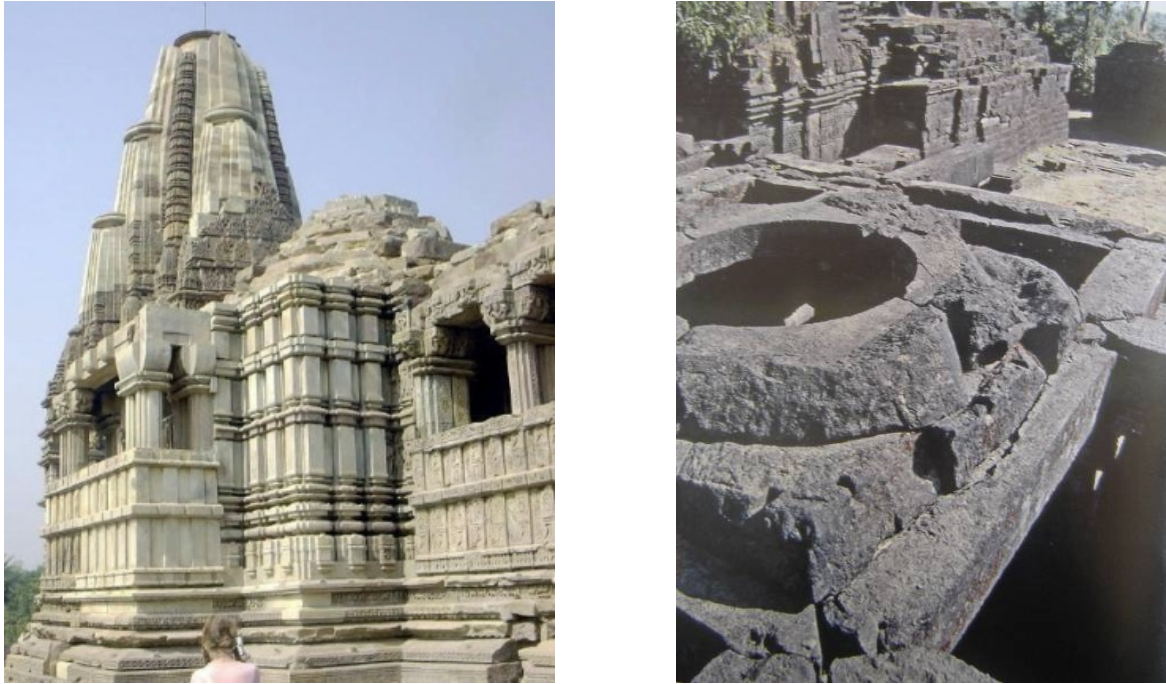


Figure 5: Corbelling system

5. THE CONSTRUCTION TECHNOLOGY OF HINDU TEMPLES

The construction of a temple is an art, a science and a complicated creative study with a blend of mathematics, logic, geography, geology, science, ecology, art, sculpting, music, light and sound, religion, social sciences and astrology.

The historical information about construction of temples which is available today is mostly inscribed in the stones slabs, metal plates, palm leaves and manuscripts. The south and the north Indian temple construction follows the same procedures leading up to the construction of the temple. Only slight differences occur due to variability of materials used for construction, the climate and availability of human resources or the social structure of a particular period.

5.1 Selection of the team

There were various organized groups of architects, artisans and workmen who were employed in the various aspects of temple construction. These groups functioned as guild or society. The techniques and skills of these associations were passed on verbally and practically from generation to generation to those in the same family or household. Today also these groups or associations exist and function in the same manner as can be seen in the Indian states of Rajasthan, Gujarat, Karnataka and Orissa and have a major role in the construction of the temples within and outside the country.

Among all the member of the association, the most foremost person involved in the construction of temple was the chief architect. Every region in the country had its own chief architect and association which are called as *sompuras* in the west, *mahapataras* in the east and *sthapatis* in the south.

The architect's work was a team work which was also bounded by the rituals performed before, during and after the construction. The construction team consisted of the four classes, (i) *Sthapati*, the main architect well versed in traditional sciences, mathematics and Shilpshastras (ii) *Sutragrahin* performs the work assigned by *sthapati* and well versed in layouts, proportion and measurements (iii) *taksaka*, who cuts and carves the stone and do the subtle detail (iv) *vardhakin* the mason or carpenter who assembles all the pieces together and several workers work under these four heads for the construction of the temple (Dagens, 1986). The team followed the instructions of the *sthapaka*, the Brahmin architect priest.

5.2 Stages of construction

The construction of temple was a long process and used to last for decades. The building of the temple was divided into three stages.

The first stage is the planning of the temple where *sthapati* with the *sthapaka* and other team members do the planning and determine the overall architectural conception of the temple. The second stage is the carving of the different parts of the temple and the *takshaka* instructs the sculptors and *shilpis* to carve the parts according to the drawings, specifications and guidelines. The third and the final stage is the assembling the parts of the temple i.e. the actual construction of the temple. Even today this same process is followed with slight variations done due to the availability of modern construction technology.

5.2.1 Stage I : Planning of the temple

This stage includes the **(i) Selection of the site**, initially an auspicious land is selected for the construction of temple as mentioned in the ancient treatises. **(ii) Inspection, insemination and levelling of the site**, The probable site for the construction is first examined for the type of soil, colour, odour, form, flavour and sound by performing some simple test on site. For e.g. a pit is dug on the site and the soil which has been taken out is put back again and checked whether the level of the packed soil is higher, same or lower. The land with the higher and the same level of packed soil are selected for the construction. When the inspections, leveling and tilling is done, the site is ready for the laying out the divine diagram or the vastupurashamandala. **(iii) Orientation, measurements and layout**, The method by which orientation was undertaken was based on the 'Indian circle method' and was based on the use of an instrument known as '*shanku-yantra*' or the 'gnomon', which is an ancient device for determining the east-west direction as well as for knowing time (Hardy, 2007). This method deeply influenced the geometry of the temple plan and its development. The nature of the main deity greatly influences the orientation of the temple. **(iv) Selection of material**, stone is considered as the most sacred building material. The stones are used in temple construction according to the availability and climate of the region. The stone selected for the construction should be of even colour, hard and perfect, pleasing to touch. The hard and even stones are used for the plinth, columns, beams and slabs. The supple stones are used for the construction of sculptures, idols, carvings etc. The preferred stones for the construction were then quarried. **(v) Quarrying of stone**, In the past the stones were quarried using wooden wedges that are driven into the rocks and then wetted to cause expansion. This in turn causes the rocks to crack and are thus cut by subsequent application of pressure and dressed. **(vi) Transportation of materials**, In the past the transportation of the stones from the quarries to the building site was done on the wooden rollers drawn by the elephants or floated on the wooden barge along the rivers and the canals.



Figure 6: Transportation and carving of stones

5.2.2 Stage II : Carving on the temple

This stage includes carving different parts of temple such as pillars, beams, brackets etc. as per the drawings and specifications. Each stone to be included in the temple construction is carved separately and later assembled together by intricate interlocking system. **(i) Cutting and carving the stone**, the team of stone mason will cut the stone block to the appropriate size, another team of carvers will give the stone a basic shape and finally the sculptors give them the final form. The joining system of each stone is pre-decided and the rough joinery details are prepared simultaneously. **(ii) Drawing in stone**, the intricate ornate carvings on the stones depend on the precise drawings. In the earlier days the drawings on the stones were made by sharpened coal piece and sharpened bamboo shoot (bamboo pencil). Stencils were made for the repetitive designs. After every phase of carving more lines are made for the carvers to detail the stones. **(iii) Polishing the stone**, the final phase of work is polishing of the final form of the stones. The polishing is done using stone bars. Once the carving and polishing is completed the pieces are stored for the final assembly of the temple. **(iv) Tools and equipments**, the basic tools, hammer and different types of chisels are used for cutting and carving of the stones. The tools are made locally and sharpened regularly in the work yard by the blacksmiths.

5.2.3 Stage III : Process of temple building

(i) Assembly of elements, final and most important stage for the construction of the temple is the assembly of all the parts together, at the site the carved parts of the temple are erected into their exact position by rope and pulley on the scaffoldings. Ramps were also constructed of timber and sand to ease the placing of heavy members. The earlier remains of ramp are found near the Temple of Brihadeshwera, Thanjuvar, which was constructed to carry the 80 tonne finial stone to the height of 60 m. **(ii) Joinery System**, In the ancient times, the traditional Hindu temples were derived from the timber and bamboo architecture. During the period of stone construction, the architectural elements and the decorative details of the temple continued to follow the timber construction details for centuries in one form or another even though the original purpose and the context was lost; see Figure 7. The timber joinery system was followed to assemble all the parts of the temple together. The major joining systems used were different types of mortise and tenon joint, and the lap joint. Another kind of joint is a kind of mortise and tenon joint, i.e. a peg is fixed between the two mortise cut out in two different stones, this joint is usually used between two courses of masonry to avoid the movement of stones due to lateral forces. In the past natural binders were used to in the joints.



Figure 7: The mortise and tenon joint and lap joint used in the masonry of Hindu temple

The construction of the temple starts with the **(i) Laying of foundation**, a pit of approximately 2 m deep is dug throughout the base and is wider than the base of the temple. The foundation is fully packed with laying of stone one above the other. **(ii) Plinth**, the stones placed above the foundation stones act as the retaining wall for the rubble compacted earth within the plinth area of the structure. The number of courses of stones at the plinth varies according to the size of the temple from 3 to 10 numbers. The top most courses on plan i.e. the stone floor of the temple, where exactly the vertical components were raised, was marked with chisel marks (mason marks) and grooves for the pillar bases without lines for rising walls and entrances. **(iii) Walls**, the main structural masonry walls are constructed as a stone composite masonry with stone, brick with lime or mud as the masonry core. The thickness of the stones varies from 300 to 4500 mm. The average thickness of the masonry wall varies from 800 to 1200 mm. Through stones are provided at regular intervals to act as ties and thus strengthen the walls. **(iv) Columns and Beams**, are monolithic structure. Columns are made up of 5 parts and all are interlocked by the mortise and tenon joints. The five parts consist of two parts of the base one part as the shaft and two as the capital of the column. **(v) Mandapa**, may be flat roofed in the south and have pyramidal superstructure in the north. The *mandapa* ceiling is built with basic beam and slab construction method. Later diminishing

patterns of nested squares were constructed by placing the triangular slabs across the corners of the square plan. The square bay of the *mandapas* were reduced to stepped pyramidal roof via triangular corner slabs or diagonal beams. (vi) *Sikhara*, is the pyramidal structure built on the *garbhagriha* of the temple. Corbelling construction system is used for the construction of the *sikhara*. The horizontal courses one above the other are stepped inwards and progressive forward to cover the space. The apex of the superstructure is mounted by a single piece of stone called as *amlaka* in the north and *sikhara* in the south. Details are shown in Figures 8 to 10.

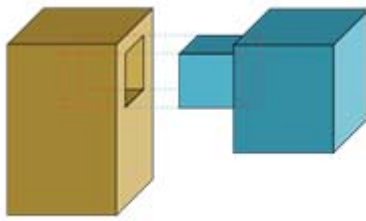


Figure 8: Column shaft fixed of with capital

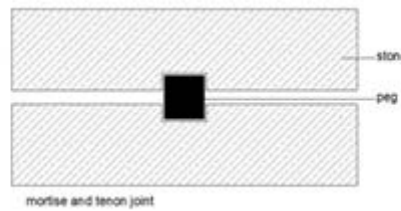


Figure 9: Arrangements of beam for mandapa ceiling

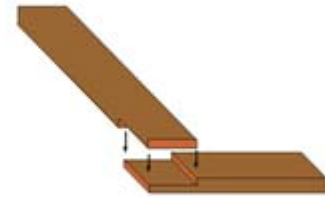


Figure 10: Construction of *Sikhara*

6. DIMENSIONAL ANALYSIS

The dimensional studies have been undertaken with respect to simple indexes of both the northern and the southern styles of Hindu temple architecture. The date of construction of these temples ranges from the 5th till 13th century. A sample of 15 temples from each style was selected. The selection was limited to 15 in number due to the limited availability of the basic drawings and information required for the analysis.

The following simplified methods of analysis and corresponding indexes are considered:

6.1. In plan area ratio of the temple

The safety of the ancient construction, namely with respect to earthquake actions, can be tentatively evaluated by calculating the in plan ratio of the building (Lourenco and Roque, 2006). In plan area ratio is the ratio between the areas of the load bearing walls and the total in plan area of the temple. The calculations show the trend of construction of the Hindu temple was massive, heavy and piled up masonry, beams and corbelling. The strength and stability is obtained by the mass supporting mass method. The ratio obtained in the tables are two to three times higher than typically required for masonry buildings (5 to 10% in modern masonry, [Eurocode 8], and 10 to 20% in old churches) (Lourenco and Roque, 2006). The average value of the in-plan area ratio for the north Indian temple is 49% (with a range from 30 to 70%), while the average value for the south Indian temple is 37% (with a range from 15 to 65%). Thus, the Hindu temples seem relatively safe and stable structures for vertical and seismic actions.

6.2 Relation between height and time of construction of the temple

The raised trend in Figures 11 and 12 shows that in the north Indian temples, the height of the shrine increased with the period of construction. The average value of the height for the north Indian temple is 15.79 m (with a range from 5 to 35 m), while the average value for the south Indian temple is 12.99 m (with a range from 5 to 20 m). It is noted that the values found are relatively low, when compared with masonry towers in Europe (up to 100 m in the Cremona Torrazo (Binda et al., 2000) and even with other buildings in India (e.g., Qutub Minar in New Delhi, which totals 76 m). Therefore the stresses in the masonry will also be relatively low.

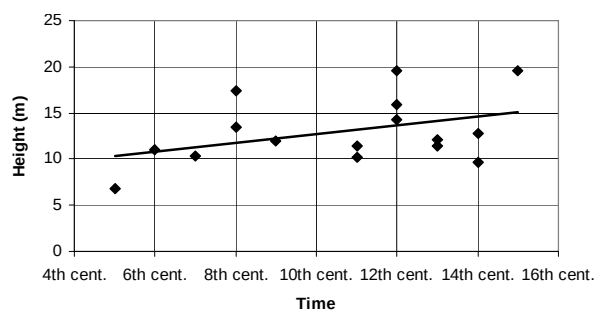
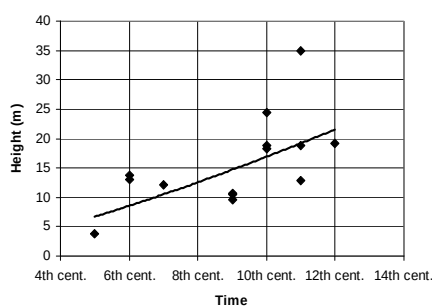


Figure 11: Height/time-North Indian temple Figure 12: Height/time-South Indian temple

6.3 Relation between slenderness and time of main shrine of the temple

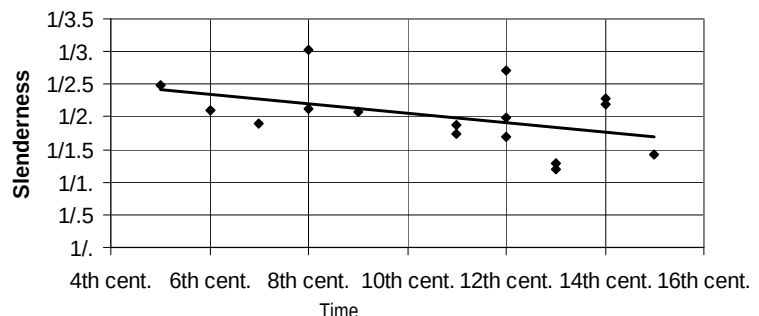
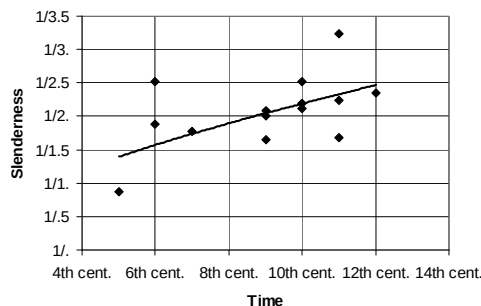


Figure 13: Slenderness/time-North Indian Figure 14: Slenderness/time-South Indian

The raised trend in Figures 13 and 14 shows that in the north Indian temples the slenderness of the shrine increased moderately with time of construction. In the later centuries, with the better building construction skills and the empirical knowledge from the trial and error building process, and to achieve more heights of the temple, the builders started to build more slender temples. In the south, the trend remains approximately constant between the values 1/1.5 to 1/3. The average value of the slenderness for the north Indian temple is 1/2.09 while the average value for the south Indian temple is 1/2.

6.4 Relation between area and time of construction of main shrine of the temple

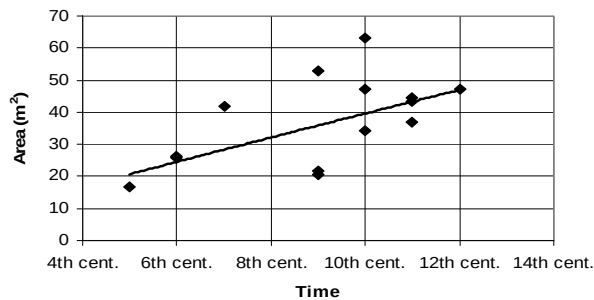


Figure 15: Area/time-North Indian temple

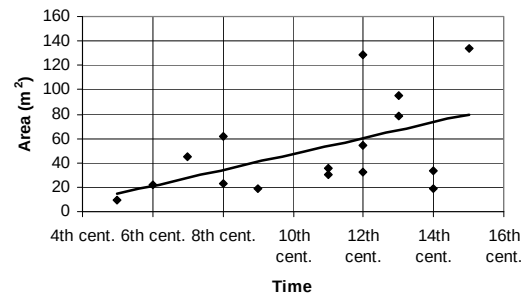


Figure 16: Area/time-South India temple

The raised trend in Figures 15 and 16 shows that the area of the shrine increased with respect to the period of construction. In the early centuries the area of the temples was low and gradually increased, possibly due to a combination of better building and material transportation techniques, wealth and size of the communities, and increasing workforce. The average value of the area for the north Indian temple is 37 m^2 (with a range from 15 to 65 m^2), while the average value for the south Indian temple is 51 m^2 (with a range from 15 to 135 m^2).

7. CONCLUSIONS

The temple architecture has given India a truly magnificent form of architecture. The construction technology used in the construction of the Hindu temple, the processes involved during its construction, the human skills required and methods utilized by architects and their team, all of this together bring out the art, science and philosophy behind the construction of the Hindu temple. Today, as new temples continue to be built the character of Hindu temples follow age old traditions, though its architectural style is influenced by the local architectural styles and locally available building material and skills.

The dimensional study of temples by taking examples from primarily 'north' and 'south' Indian temples is an attempt to graphically analyse the structures with respect to its structural stability. The finding of the above studies is that the stability of the temple structure depends mainly on the geometrical compatibility of the elements with respect to the load applied rather than material failure. The analysis therefore constitutes an important step in safety assessment of this kind of structures. The data concerning the main geometrical property of temple from the 'north' and 'south' of India here have been collected and elaborated through some specific though limited number of examples. In spite of the limited number of samples it is possible to find some interesting trend even though the absence of a statistical validity constitutes a starting point for future works concerning the stability analysis of the temples."

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