A STUDY ON THE ENGINEERING ASPECTS OF TRADITIONAL ARCHITECTURE

A THESIS

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Dedicated to the Fond Memory of my Beloved Parents

THESIS CERTIFCATE

This is to certify that the thesis entitled '**A STUDY ON THE ENGINEERING ASPECTS OF TRADITIONAL ARCHITECTURE'** submitted by **Rajasekhar P.** to the Cochin University of Science and Technology, Kochi for the award of the degree of Doctor of Philosophy is a bonafide record of research work carried out by him under my supervision and guidance at the Division of Civil Engineering, Faculty of Engineering, Cochin University of Science and Technology. The contents of this thesis, in full or in parts, have not been submitted to any other University or Institute for the award of any degree or diploma.

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DECLARATION

I hereby declare that the work presented in the thesis entitled **'A STUDY ON THE ENGINEERING ASPECTS OF TRADITIONAL ARCHITECTURE'** is based on the original research work carried out by me under the supervision and guidance of Professor (Dr) Babu T Jose, Emeritus Professor, Division of Civil Engineering, School of Engineering for the award of degree of Doctor of Philosophy with Cochin University of Science and Technology. I further declare that the contents of this thesis in full or in parts have not been submitted to any other University or Institute for the award of any degree or diploma.

Kochi – 682 022 **Rajasekhar P.**

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ABSTRACT

Key words: *Vastu, Vedic Architecture, Manushyalacandrika, Angula, Hasta, Site selection, Orientation, , Facing, cardinal directions, slenderness ratio, Dynamic Vastu , Natyagruha, Theatre , sustainability, Green buildings, Kerala School, Mādhava, Gnomon, Tantrasamuccaya.*

The present study is on ‘Engineering Aspects of Traditional Architecture’. The present study aimed only at analyzing the rational and scientific content that are dealt in Vastu texts leaving aside the ritualistic, religious and mystic components.

The traditional architecture is generally known as ‘Vastu vidya’. India has a rich tradition of Architecture and Building Science from time immemorial. ‘Śilpaśāstra’ is also synonymously used to denote Vastu tradition. The Vāstuvidyā tradition of Indian subcontinent is very old and its spread was from Volga region (Russia) to Philippines in the East, Himalayas in the North to Sri Lanka in the South.

The styles of Architecture and mode of construction in Indian sub-continent varied giving rise to broadly two styles namely South Indian and North Indian. Of South Indian tradition, Kerala style is unique. In the present study emphasis is given to Kerala stream of traditional architecture.

In Vastu tradition theory and practice coexisted and reference books both in Sanskrit and vernacular are many. For the present study all major treatises are referred to. Also recent translations, research studies and relevant papers are reviewed.

As many studies have taken place on architectural and planning aspects dealt in Vastu, the present study focused more on other civil engineering aspects such as geotechnical, construction materials and structural topics. A new area of construction management is also explored. Since the Vāstu tradition is essentially a sustainable model; the present study is also extended to this aspect also. Limitations of current practices in Vāstuvidyā are identified. The need and scope of reorientation of Vāstuvidyā to meet the present day requirements are discussed. The deficiencies of Vastuvidya tradition are also identified and included.

In the present study certain historical aspects, growth of Vastu vidya under the influence of Kerala mathematical scholarship of medieval period is also studied. This is an unexplored area with respect to Vastuvidya. Under special structures, the Natyagruha construction in Nāṭyaśāstra is studied and some findings are presented.

The Vastu texts have mentioned outstanding results and dictions with regard to building design and construction, but the methodology of derivation of these results are unknown. As a part of the present study attempts are made to bridge this gap providing mathematical derivations and structural computations. The design philosophies, principles and approach are also studied and 'tautological approach in Vastu tradition has been identified and highlighted.

Considering the vastness and depth of the Vastu texts there is considerable scope for further research studies.

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GLOSSARY

Angula	Sub division of Hasta (3 cm)
Avanata	Device to fix horizontality
Chathura	Square
Diknirnaya	Determination of cardinal direction
Hasta	Traditional measuring unit (72 cm)
Khanda	A Quadrant
Kishku	Traditional measuring scale (24 Angulas)
Lupa	Rafter
Natyagruha	Theatre
Nepathya	Green room
Pada	A Cell in graphical representation
Paramanu	Atom
Prakruthilupa	Common rafter
Sanku	Gnomon
Sutra	Measuring thread
Thryasra	Triangle
Utharam	Wall plate
Vamata	Eave Reaper
Vāstu	Traditional Indian building science
Vikrushta	Rectangular
Vikruthilupa	Slant rafter
Yava	Sub division of Angula (3/8 cm)

ABBREVIATIONS

ABB	*Āryabhaṭīyabhāṣya*
AM	Ante Meridiem
AS	*Āpastambasūlbasūtra*
BCE	Before the Common Era
BS	*Bṛhatsaṃhitā*
BS	British Standard
CE	Common Era
Cent	Century
cm	centimeter
cm/sec	centimeter per second
CPWD	Central Public Works Department
CRZ	Coastal Regulation Zone
FAR	Floor Area Ratio
ft	feet
g/cc	gram per cubic centimetre
GPS	Global Positioning System
GWL	Ground Water Level
hrs	hours
IS	Indian Standard
KBR	Kerala Building Rules
km	killometer
kN/m^2	kilonewton per square metre
kN/m^3	kilonewton per cubic metre
m	meter

m/sec	metre per second
MC	Manuṣyālaya Candrikā
mm	millimeter
MS	Mānasāra
MVA	Maharishi Vedic Architecture
N/mm^2	newton per square millimetre
NBC	National Building Code
NE	North-East
NS	*Nāṭyaśāstra*
NW	North-West
PCC	Plain Cement Concrete
PM	Post Meridiem
RCC	Reinforced Cement Concrete
RV	Rig-Veda
SE	South-East
sec	second
SPT	Standard Penetration Test
SR	Śilparatna
SW	South-West
TS	Tantrasamuccaya
VV	*Vāstuvidyā*
µm	micrometer

NOTATION

English Symbols

A	Aṅgulas
b.	Birth (year)
b	Breadth of beam
C	Coefficient of percolation
c.	Circa
D	Least lateral dimension of column.
D_b	Least Dimension of column at bottom
D_t	Least Dimension of column at top.
d	Depth of beam
E	Young's modulus
f	Allowable stress
f_{ck}	Characteristic strength of concrete
H	Hasta
h	Head
I	Intensity
I_B	Intensity of incident ray
I_C	Intensity on ground
k	Coefficient of permeability
K	Form ratio
L	Height of column.
l	Span of beam

M	Bending moment
mm	millimeter
N	Newton
p	Maximum bearing pressure
Q	Quantity of water percolates
R	Trijya (Radian expressed in minutes, and subdivisions in sexagecimal system)
t	time
r	Radius of gyration

Greek Symbols

α	Depression angle
β	Angle of incidence
γ_d	Bulk density
δ	Maximum deflection
λ	Sun's instant declination
σ_c	Direct stress
σ_e	Euler's stress
φ	Latitude of the place
ω	Maximum declination

Miscellaneous symbols

°	Degree
%	Percentage
#	Number

CHAPTER 1

INTRODUCTION

India has a rich tradition of Architecture and Building Science from time immemorial. From the Vedic period itself, both theory and practice have developed in this field under the umbrella of Vedic literature corpus. The theory and philosophy of Indian Building Science or Sthāpatyaveda (the knowledge of installation) have been recorded in the form of exclusive texts or chapters in several books. Indian building science or Architecture is generally known as Vāstuvidyā or Vāstuśāstra. The term Vāstu is derived from the root 'Vas' in Sanskrit which means to dwell and correspondingly it denoted 'Building Technology'. Several texts are also titled under the term 'Śilpaśāstra' which has derived its root from Śilpa which literally means sculpture, and could be related more to Architecture and Iconography.

As cited earlier the Vastuvidya tradition of Indian subcontinent is as old as Vedas and *Sthāpatya Veda,* which deals with this tradition is supposed to be an annexure of *Atharvaveda*. Chapters on Vastuvidya could be found in many Purāṇas, Saṁhitās and Śāstras. For instance, *Padmasaṁhitā, Bṛhatsaṁhitā and Matsyapurāṇa* have dealt extensively on Architecture, sculpture and construction. The *Nāṭyaśāstra* and *Arthaśāstra* have also included chapters on this topic. Incidentally *Nāṭyaśāstra* of sage Bharata is a text on Dramaturgy and *Arthaśāstra* of Kautalya is a text on political economy.

The styles of Architecture and mode of construction in Indian sub-continent varied giving rise to broadly two styles namely South Indian and North Indian. This classification can be seen in the Vāstu texts itself in classifying Prasadas (the main part of any temple where deity is installed or in other words the 'sanctum sanctorum' of the temples) in to Nagara, Dravida and Vesara (Sastri, 1922). Here Dravida broadly refers to South Indian style. This South Indian style again has many local variants and Kerala style is one of the prominent and unique under South Indian style. The local styles have evolved based on its geography, climate and availability of building materials. Under the broader category of Indian Tradition in all aspects of human endeavors, we could identify the blend of Indian tradition and local tradition. In arts and music, it is termed as '*Mārgi*" and '*Deśi*' traditions. In similar terms, building science has also a blend giving rise to a distinct style. These local styles are also supported by theoretical backup through texts written in Sanskrit as well as in regional languages. Apart from this, there is also localized knowledge base which is not recorded anywhere but orally transmitted and preserved. This is called 'Nāṭṭarivu' in local parlance. Thus there exist two streams of knowledge with regard to our traditional building technology; one recorded and specified in texts and the other orally transmitted by practitioners through ages. This theory and practice have some conflicts and incompatibilities when put to practical use and those are usually addressed in later writings.

As it is generally accepted, the settlement of the Vedic people from North, occurred in Kerala in the early centuries of 1st Millennium and is reflected in the legendary story of Paraśurāma establishing sixty four grāmas (villages). Historians are now of the opinion that this settlement stabilized between the period 3rd and 5th century CE

(Menon, 2005). This is clearly evident from the period of Vararuci (4th Cent.) and date of commencement of Peruvanam pooram. (*"Āyatuśivalokam naḥ"* –kalikkettu denoting the starting of Peruvanam pooram: 583 CE). The oldest and most popular Astronomical table is known as Vararuci vākyas as it was expounded by Vararuci. He is also supposed to have introduced the 'Kaṭapayādi' system in Kerala Mathematics tradition which helps to memorise various constants, coefficients and factors in versified form (Parameswaran, 1990). After this period, nearly for thousand years, till the arrival of Europeans, Kerala enjoyed a socially and politically tranquil environment blessed with economic stability and social status. With generous support and encouragement from Kings and Chieftains, many scholars engaged in popularising Vedic rituals, Sanskrit learning and Sanskrit scientific literature. The climate and the land with abundant natural wealth, conducive for a healthy and peaceful living, improved their quality of life. Instead of leading a lazy and luxurious life under feudal authority and abundance, at least a sizable number engaged in literary and other intellectual pursuits producing remarkable achievements. The contributions in the field of Mathematics and Astronomy by Saṅgamagrāma Mādhava (14th Cent.), Vaṭaśśeri Parameśvara (15th Cent.), Kelallur Nīlakantha Somayāji (16th Cent.) etc. are worth mentioning (Joseph, 2009). This naturally gave birth to, many schools of learning and research centres in different fields like Ayurveda, Literature, Arts, Mathematics, Astronomy, Astrology, Vastuvidya etc. Whether it is Ayurveda or Vāstuśāstra, it is worthy to mention that Kerala scholars never limited their studies on traditional texts by mere chewing the cud, but critically examined these sciences, appended, updated, improved and modified to suit their times and more often went ahead of their times (Sundareswaran,2018). Koodallur and Kodungaloor could be cited as best examples of such schools.

After colonization, in every part of India, the building technology underwent a rapid transformation by both forceful introduction of European styles by officials and general adoption of the European styles by public under the impression that everything western is superior and local is inferior. The mystic and occult nature of the Vāstu texts aggravated the situation as those who obtained modern education viewed Vāstu tradition totally as a 'pseudo-science' and often categorized under the realm of 'superstition'. This pushed the traditional wisdom and indigenous treasures of knowledge of our civilization developed through centuries, outside the formal education system. This marginalization along with its mystic halo prevented systematic scientific studies on the subject separating out its elements of belief system and elements of 'science' in modern terms.

Currently, most of the Vāstu practitioners, also give emphasis to the 'belief system' of Vāstu keeping its mystic nature rather than connecting it to science and technology. In other words, secular and scientific thoughts in the Indian Building Science were never systematically sieved out and studied comprehensively. Only in the past three decades, in India, some studies in this regard have appeared. This might have been triggered by several International studies challenging the so called 'Euro-Centralism' in Education, Science and Technology (Joseph, 2000). In search of non-European roots of modern sciences, they have established that many modern scientific theories and findings are extensions and developments of scientific ideas that existed in Arab, Indian or Chinese cultures. Thus it is now established that Europeans cannot claim the sole monopoly of creativity and original thinking. The need for looking back was not merely to find a pleasure in saying we had also a glorious past but to search for a different pedagogical and epistemological approach that existed in the ancient knowledge domain. At least in Mathematics this has been by and large established. During recent years regarding the origin of infinitesimal analysis and Calculus have been established (Raju, 2001), If we borrow the words of the renowned writer, Vaikom Muhammad Basheer (1908-94), definitely at least in some spheres of knowledge Indians also can proudly say '*nte uppappakkoranayundarnnu'* (my granddad had an elephant).

The release of the widely read book '*Crest of the Peacock*' on Non-European roots of Mathematics (2000) written by the doyen in the field by George Gheverghese Joseph could be considered as a milestone in the history of Indian sciences especially Kerala tradition in Mathematics and Astronomy. Another book of the author titled '*Passage to Infinity*' (2009) also had an impact on triggering interest in traditional sciences and initiating scientific studies separating out the non-secular and mystic elements. Vastuvidya also had a revival during Nineties. As a result of this, many Vāstu Pundits and Vāstu experts appeared throughout India and unfortunately most of them were quacks exploiting the 'beliefs' of common people.

Regarding serious and scientific studies at international level, Maharishi Mahesh Yogi initiated programmes under the tutelage of Vedic studies proclaiming Vāstuśāstra as Vedic Architecture (Neil, 2002).

In Kerala also, two accomplished Professors from civil engineering faculty of NIT Calicut took initiative to start an institution named Vastuvidya Prathistan (1993), to preserve the unique and continuous tradition of Kerala Vāstu. Similarly Kerala Government also started a school in Aranmula naming it as Vāstuvidyā Gurukulam.

(1993). Even now these two institutions mainly connect the qualified Engineers and Architects with Vastuvidya tradition of Kerala. In Sree Sankaracharya University of Sanskrit, Kalady from its inception in 1993 also have a separate department of Vastuvidya and several studies have been undertaken under the guidance of former head of the department, Professor Dr. P. V. Ouseph. Traditional families like Kanippayyur, Vezhapparambil, and Cheruvally etc. still have prominent practitioners with their inherited knowledge attained through Gurukula system.

In last twenty years many studies and research works have been undertaken by Engineers and Architects. Most of these studies are limited to Architectural and planning aspects related to Vāstu or studies on specific texts. Thus there is a need of a study emphasizing other engineering aspects and hence the objective of this study is formulated accordingly.

1.1 OBJECTIVES OF THE PRESENT STUDY

The present study aims at the systematic scientific study of the Engineering aspects of traditional Architecture with special reference to the Kerala tradition. Under the study, the theory and practice of Kerala Vāstu tradition and local wisdom related to the building sciences are mostly covered. The elements of belief system and non-secular elements are not included in the scope. Each aspect of the traditional building itinerary is studied and analyzed in terms of modern Engineering theories and practices.

Going through the available literature, as stated above it is seen that most of the studies on traditional building sciences have taken place on its Architectural and Planning aspects. Going through literature, it has become a beaten area in Vāstu tradition owing to many studies and papers. Hence in this study emphasis and focus is given to other Civil Engineering aspects such as Geotechnical and Structural topics. Philosophical affinity of Indian tradition to nature has made Indian building tradition more environmental friendly. Thus, Vāstu tradition has embedded many sustainability aspects in its theory and practice. Modern Green Building concept also has many parallels in Vāstu tradition. Hence this study is also extended to this aspect considering its contemporary relevance.

Limitations of current practices in Vāstu tradition are identified. The need and scope of reorientation of Vāstu tradition to meet the present-day requirements are framed and a model in this respect is presented. The Limitations of Vāstu tradition is also identified and presented.

Thus the objective of the study can be summarized as follows:

- Study on Civil and Structural Engineering Aspects in Vāstu and its comparison with modern engineering practices and theory.
- Comparison of sustainability aspects in traditional and current concepts
- Listing out the problems of practicing Vāstu.
- Identifying the limitations and lacuna in Vāstu tradition as a science**.**
- Suggest improvements and changes needed to make Vāstu more dynamic, universal and contemporary.

1.2 LIMITATION OF STUDY

The present study is confined to the Vāstu practice followed in Kerala region and only a few references are made to structures and practices outside the region.

Mainly the tradition of Vāstu related to buildings only is included. Vāstu is comprehensive and it includes not only the architecture and engineering of residences, places of worship for Hindus, Buddhists, Jains etc., palaces, buildings of special purpose buildings like Theatre, Concert halls etc. but also the design and construction of Villages, Towns, Ports, Forts, Furniture, Iconography, Mural paintings, Sculpture etc. (Sastri, 1990).

1.3 ORGANISATION OF THE THESIS

This study titled 'A Study on the Engineering Aspects of Traditional Architecture' is divided into eleven chapters. The first chapter deals with the Introduction to the topic of study. Objectives and limitations of the study are also included in this chapter. The main objective of the study is to analyse the engineering aspects in Vastuvidya tradition. As the Vāstu tradition is a mixture of Architecture, Sculpture, Engineering, Astrology, Iconography, Astronomy, Mathematics etc., the non-secular and socially irrelevant aspects are separated out and only rational and scientific aspects are studied and its parallels with modern engineering codes and practices are compared. The study also has identified the defects, limitations and lacuna in the Vāstu tradition. The current problems in Vāstu practice are also brought out in this study.

Chapter two deals with literature survey comprising of primary texts on Vāstu tradition mainly in Sanskrit and its traditional commentaries in Sanskrit. Translations with explanatory notes on various traditional texts appeared in last hundred years after the advent printing. Independent Vāstu texts written in recent years are based on traditional texts and case studies. Research studies on various topics in Vāstu tradition, research papers on various aspects of Vāstu tradition are the other sources of references. Meetings and discussions with Vāstu Practitioners and experts and interactions during seminars and conferences also has helped to gather information.

The third chapter is on planning and development in Vāstu. In this chapter, site selection, determination of cardinal directions, orientation principles, building location, room layout, proportions of length and breadth are included. Its comparison with modern engineering practice especially with National Building Code and other standards are done.

The fourth chapter deals with construction management and construction materials in Vāstu. This deals with construction management practices that existed in ancient India and its comparisons with modern systems is also done. Here site Organisation, quality control, need for worker's motivations etc. discussed in traditional texts are included. The construction materials mentioned in traditional texts are also dealt with in this chapter.

The fifth chapter is on super structure construction and structural engineering in Vāstu. Design and detailing of columns, walls, beams, rafters etc. that are found in Vāstu texts are by and large an unexplored area and studies comparing the same with modern engineering theories are very few.

Regarding design and construction of special structures like theatre deserves special attention and this is included in the Chapter six under the title 'Special Structures in Vāstu'.

Chapter seven deals with soil mechanics and foundation in Vāstu. Soil mechanics is one of the young branches in modern engineering. Surprisingly various soil testing methods and soil property evaluation can be found in Vāstu texts. It is interesting to note that a humble beginning of the one of the most popular soil testing method, the Standard Penetration Test (SPT) could also be traced in Vāstu books.

Chapter eight is on the influence of medieval Mathematics on Kerala Vāstu. Kerala witnessed an unprecedented growth in Mathematics and astronomy during 14^{th} to 18^{th} century CE. Many Vāstu scholars and authors of renowned texts during the same period had close association with the doyens in Mathematics. This has resulted in improving certain aspects mathematically in Vāstu which is not seen in the texts belonging to other regions. Thus, it is concluded that Kerala scholars have made original contribution to Vāstu making Vāstu tradition of this region unique.

Chapter nine deals with sustainability, ecology and environment in Vāstu. Because of the underlying philosophical affinity, Vāstu and sustainability concepts have lot of similarities in its content and approach. Now Vāstu designs have got international attention and acclaim as an alternate for the Green buildings under the tutelage Vāstu Green, the building in tune with Natural Law based design and construction.

Chapter ten takes a look at the current Vāstu practices. Current Vāstu practice gives more emphasis on the ‘belief systems’ in Vāstu tradition. For this, the Vāstu practitioners knowingly or unknowingly promote a mystic halo for the subject. Modern designs are made and these designs are then sanctified by Vāstu pundits by changing certain dimensions in accordance with *‘Āyādiṣaḍvarga’* table. Thus most of the Vāstu designs lack the soul of Vāstu philosophy.

Finally the Chapter eleven presents the summary, conclusions and findings of this study.

CHAPTER 2

REVIEW OF LITERATURE

Numerous Sanskrit texts are available on Vāstu tradition and allied subjects. Of these twenty-one texts are found mentioned in the acclaimed text named Manuṣyālaya *Candrikā* (MC) written in c.1530 CE. Most of the texts mentioned in MC are fortunately not lost in antiquity and that too available in printed form.

The printed versions of important Sanskrit works were released mostly in the early 20th century, by dedication of scholars under the Royal patronage of Travancore, Cochin, Mysore and Baroda. Collecting manuscripts and making out an error free 'suddha patham' is a herculean task which calls for ripe scholarship and much perseverance. Credit must go to Ganapathi Sastri (1860-1926), Sambasiva Sastri, Shama Sastri, Ramakrishnakavi etc. who strived hard in making these precious texts available to the present generation. Under the Trivandrum Sanskrit Series itself, 111 books were printed and published from manuscripts which included six prominent reference texts that are mentioned in *Manuṣyālaya Candrikā* (MC) besides MC (TSS-056) itself. Another most popular text, *Śilparatna* (TSS 075 & TSS -098) were also published in this series in two parts. The other texts published in this series *Vāstuvidyā* (TSS-030), *Mayamata* (TSS-065), *Īśānaśivagurudevapaddhati* (Part-1: TSS-069 & Part2: TSS-083) and *Tantrasamuccaya* with commentary (TSS-067 & TSS 071) and *Vishnusamhita* (TSS-085) are connected with Vāstu tradition and that are referred in MC.

Manuṣyālaya Candrikā mentions the names of around twenty books which must have been the most referred in those days and followed with reverence. Hence tracing these texts has more relevance while studying the Vastuvidya tradition of Kerala. *Manuṣyālaya Candrikā* lists the above texts in the following verse (Sastri, 1917).

> mayamatayugalam prayogamañjaryapi ca nibandhanabhāskarīyayugmam/
> manumatagurudevapaddhatiśrīhariyajanādimahāgamā jayanti/
> mārkaṇḍeyayugaṃ parāśaramurāriproktaratnāvalīsārān kāśyapa
> viśvakarmamatayugmādyaṃ kumārāgamam/
> savyākhyāṃ harisaṃhitāṃ vivaraṇādyaṃ vāstuvidyādikān dṛṣṭvā
> tantrasamuccayoktam anusṛtyaivātra saṃkṣipyate// MC 1:7

Literal translation: *Referring to Mayamata (2 books), Prayogamañjarī, Nibandhana (2 books), Bhāskarīyam (2 books), Manumata, Gurudevapaddhati, Śrī Hariyajanam, other Āgamas. Mārkaṇḍeyam (2 books), Ratnāvalī of Pārāśara and Murāri, Kāśyapamatam, Viśvakarmamatam, Kumārāgama, Harisaṃhitā with commentary, Vivaraṇam, Vāstuvidyā and finally according to Tantrasamuccaya (TS), this book is prepared in brevity.*

Thus, categorically *Manuṣyālaya Candrikā* has mentioned that it is prepared based on TS after referring previous texts as mentioned. Here two *Mayamata* texts have been mentioned. But only one *Mayamata* is now available. The available *Mayamata* is a south Indian text probably written during 8th century and is/was very popular in Tamil Nadu. It is an exhaustive text with thirty-six chapters and the summary of chapters are given in the preamble. In 1976, this was translated to French. Probably the first printed edition of *Mayamata* was published from Trivandrum, *Mayamata* of Mayamuni edited by Ganapati Sastri (1919). A Malayalam translation of *Mayamata* has been recently released (Mohanakshan and Manoj, 2015). Other *Mayamata* remains untraced but a text called *Mayasaṅgraha* is available. Probably this may be the text which is referred to in the above verse. Otherwise this could be *Mayamatasangraha* written by Kannamacharya, which is identical with *Mānasāra*. Here it may also be noted that *Manasara* is not mentioned in *Manuṣyālaya Candrikā* and thus one of the *Mayamata* could be *Mānasāra* (Acharya, 1980).

Prayogamañjarī is again a text which deals with rituals in temple which contain Vāstu references related to temple construction *Nibandhanas* refer to *Mahānibandhana* and *Śaivāgamanibandhana*. *Mahānibandhana* contains *Sarvadevapratiṣṭhāprakāśam* and *Anuṣṭhānaprakāśam*. Two books of *Bhāskarīyam* are also mentioned. These are the books of Bhaskara I and Bhaskara II respectively. Both are mathematical texts. Bhaskara I (c.600-c.680 CE) has written two books *Mahābhāskarīyam* and *Laghubhāskarīyam* (Shukla, 2003). Bhaskara II (1114-1185 CE) is the well-known mathematician who authored *Līlāvatī* and his famous treatise is *Siddhāntaśiromaṇi* (Panicker, 2006).

Another text referred as *Manumata* is not definitely the well-known *Manusmṛti*, but some other text related to Vāstu vidya. Other possibilities are *Mānavaśūlbasūtra* (c.750 BCE) or *Mānavavāstulakṣaṇam*. Further references to confirm the above are not able to trace.

Gurudevapaddhati also known as *Īśānaśivagurudevapaddhati* is popular in Kerala. It is published from Trivandrum and edited by Ganapathy Sastri (1920). This is a monumental work in Tantra and its author is Isanasiva Gurudeva (c.1150 CE) who hails from Kerala.

Hariyajanam refers to *Padmasaṁhitā* in Pancaratra (Agamic texts) (Sampath, 1974). *Mārkaṇḍeyayugalam* refers to two texts ie *Mārkaṇḍeyapurāṇa* and *Mārkaṇḍeyasaṃhitā*. Its printed version is available which are published by Tirupati Devasthan.

Two *Ratnāvalī* texts have been referred in *Manuṣyālaya Candrikā*. One is written by Pārāśara and the other by Murāri. The other text referred is *Kāśyapaśilpaśāstram* which has many commonalities with Mānasāra (Acharya, 1946).

Two texts authored by Viśvakarma are mentioned. *Viśvakarmavāstuśāstra* (*Viśvakarmaprakāśa*) and *Viśvakarmaśilpa* (*Viśvakarmaśilpaśāstra*) are the two texts (Pardeshi, 2016). Of these *Viśvakarmavāstuśāstra* has been published from Tanjore with traditional commentary (Sastri, 1990). *Kumārāgam* is another text which has been got mentioned in MC but it is untraceable. *Viṣṇusaṃhitā* with interpretations has been mentioned. Here the mentioned interpretations are Hāriṇī etc. (Cheruvally, 2016). The other books are *Vivaraṇa* and *Vāstuvidyā*. *Vivaraṇa* is also not seen to have published in that name. However, it could be concluded that *Manuṣyālaya Candrikā* referring to the commentary on Bhaskara's *Lilavati* by Vatassery Parameswara (15th Cent.) which is known as *Vivaraṇa*, considering the association of the author of MC, Tirumaṅgalattu Nīlakaṇṭhan with Kerala School of Mathematics. *Vāstuvidyā* is the popular text in Kerala and it appears to be a construction manual more than a design guideline (Sastri, 1913).

Another popular and most referred book is *Mānasāra* (MS) and its English translation, 'Architecture of Manasara' (Acharya, 1946). The translation is exemplary, doing full justice to the original work. This book is not seen referred to in *Manuṣyālaya Candrikā* probably due to the fact that the same was not popular in South. Otherwise this book might have been known in some other name in Kerala.

However, the mentioning of Kerala in the Chapter 30 by the same name in MS is interesting. Nearly forty major treatises are available in Sanskrit and as many or more in vernacular languages in different parts of India on Vastuvidya. Another most referred book is Samarāṅkaṇasūtradhāra written by Bhoja (1000-1055 CE) is comprehensive text running to eighty three chapters (Sastri, 1924).

Out of eighteen Purāṇas, seven of them have included chapters on Vāstu similar to other Vāstu texts, (Acharya, 1980). *Agnipurāṇa*, (Rudran et al., 2014) and *Mārkaṇḍeyapurāṇa,* (Menon and Narayana, 2014) has sixteen chapters on Vāstu and *Matsyapurāṇa* (Sarala, 2014) and *Bhaviṣyapurāṇa* (Kamaladevi, 2014), has four Chapters each. The other Purāṇas containing at least one chapter is on Vāstu. Skanda, Vayu (Lakshmikutty, 2014) *Garuda* (Idakidath, 2014) and *Narada Purana*. The Period of Purāṇas are estimates as from 300BCE to 400 CE. *Nāṭyaśāstra* and *Bṛhatsaṁhitā* are also worth mentioning in this regard. *Arthaśāstra* mentions about Vastuvidya and its rules in several places (Jaya, 2011).

Cennās Nārāyaṇan Nampūtirippāṭ (b.1428) who wrote *Tantrasamuccaya* (TS), the code of rituals for Kerala temples has included a chapter (second chapter) on Vāstuvidyā depicting various aspects of temple construction. The TS was a milestone in the history of Kerala Tantric tradition as it surpassed or survived all the previous books like *Īśānadevagurudevapaddhati*, *Prayogamañjarī*, *Pūtayūrbhāṣa* etc. Based on the chronogram '*chelluradhipathijneyam*, in Pūtayūrbhāṣa itself, the year of its composition is arrived as 1342 CE (Elayath, 2006).

The text titled '*Vāstuvidyā'* of unknown authorship most probably might have been written before *Tantrasamuccaya*. And the text seems to a practical guide and this must be the reason for its popularity among craftsman.

Tirumaṅgalattu Nīlakaṇṭhan (c. 1530 CE) wrote *Manuṣyālaya Candrikā*, based on *Tantrasamuccaya*. It is one of the most popular and authentic literature on Kerala Vāstu tradition. Tirumaṅgalattu Nīlakaṇṭhan hailed from Tirumangalam near Trikantiyur. His place of birth as Vettathunadu is very clear from the salutations he has mentioned in MC. He was a disciple of Nīlakantha Somayāji (1444-1545 CE), the doyen of Kerala School of Mathematics and co-student of Tuñcatteẕuttaccan and Jyeṣṭhadeva who wrote *Yuktibhāṣā*. Tirumaṅgalattu Nīlakaṇṭhan has two other books to his credit, *Mātaṅgalīla* (On Elephants) and *Veṭikampavidhi* (Pyrotechnics) (Vadakkumkoor, 1962).

MC is followed by *Śilparatna* (SR) authored by Śrīkumāra (1635 CE). Though SR was authored as per the directions of King Devanārāyaṇa of Amabalappuzha, the author hails from Chiramekkadu near Kunnamkulam. It is believed that *Bhāṣāśilparatna* is also of the same author. Most of the verses in the *Bhāṣāśilparatna* (Cheruvally, 2015) were known by heart by all traditional Śilpins till recently.

The Vastuvidya tradition as cited earlier has its roots in *Vedas* and *Sthāpatya Veda* may be the primary source of this knowledge system. Going through the original texts, it is seen that the mode of treatment of the subject and basic philosophy and approach is same. In most cases, the ideas in old texts are presented and it is only the style of presentation which is different. Instances of quoting the same verses from old texts are also common. Thus, many texts are mere compilations of relevant portions from different sources.

2.1 MAJOR CONTENTS OF THE VĀSTU TEXTS

Most of the Vāstu texts deal mainly with the following topics in general.

- Bhūparigraham: Site selection and qualities of good plot.
- Bhūparīkṣā: Soil Testing etc.
- Diknirṇaya: Determination of cardinal directions
- Mānanirṇayam: Metrology, Units of measurement and scales
- Khaṇḍaparikalpana Dividing in to four quadrants.
- Pādavinyāsam: Dividing in to padas, veedhis and marmas vital points
- Vāstupuruṣamaṇḍala: The cosmic projection into the plot.
- Sthāpatyalakṣaṇam: Job description and skillsets of silpins.
- Ayādiṣaḍvarga: Determining the merits of selected dimension by six rules
- Śālāvinyāsam: Layout and planning of building
- Aṅga kalpana: Various parts of building and its proportioning
- Alaṅkāra vidhi: Architectural finishing and decorative works.

Almost all texts discuss about 'Bhūparigraham'. In *Manuṣyālaya Candrikā* the first chapter describes the subject. However, in the succeeding texts like *Mānasāra*, *Mayamata* and *Śilparatna*, selection of site is dealt with in the fourth Chapter. In Vāstuvidyā, second chapter deals with the subject under the title 'vasudhalakshana'.

Bhūparīkṣā or different soil testing methods are dealt in all most all texts like *Manuṣyālaya Candrikā*. Other puranic and encyclopaedic texts like *Matsyapurāṇa* and *Bṛhatsaṁhitā* also describe soil testing. But in the popular text, *Vāstuvidyā*, Bhūparigraham is discussed in minimum limiting to desirable slopes of the plot and soil testing is not at all discussed. On reading *Vāstuvidyā* in detail, it appears that the text deals more with constructional aspects. To put it in a nutshell, it is a practical guide and hence rare details on joints, tile making, graphical method of finding length etc. are discussed in detail.

Diknirṇaya (Method to find true geographical directions) is invariably discussed in all texts. It is found in mathematics and astronomy texts also. One of the most ancient references to this method could be seen in the *Kātyānaśūlbasūtra* (300 BCE). Ancient texts also mention about some correction (numerical correction depending up on the month of experiment) indicating that the effect of declination affecting the result were known to them. However, *Manuṣyālaya Candrikā* (MC) mentions a unique method of determining the cardinal directions. Other texts like *Śilpiratna* (Cheruvally, 2015) and *Vāstuvidyā* (Cheruvally, 2007) have suggested methods to calculate the error due to declination upon measuring length of shadow etc. *Tantrasamuccaya* (Kanippayyur, 2003) has suggested another unique method.

2.1.1 Units of Measurement

Vāstu tradition has its own metrology. The basic units of measurement can be seen in Ṛgveda (3000BCE) itself (Dongree, 1994).

Though Vāstu tradition had well-defined units and scales from ancient times, it had many variants with respect to locality and period. This occurred because of the fact that our purview of consideration is the vast area of Indian subcontinent which was divided politically into innumerable provinces and numerous books were written during a long span of at least 3000 years. In course of time, many transformations took place with respect to location. This made it difficult for the historians to establish the exact correlation in terms of current units. Thus, while interpreting many measurements in modern terms different opinions could be seen. For instance, the unit of measurement Yojana has been used, to denote different lengths in different era and in different localities. According to *Suryasiddhānta*, and *Āryabhaṭīya* one Yojana is approximately 8 km and according Kerala School one Yojana is 12.7 km, Parameśvara (14th Cent.). Some of this could be an erroneous interpretation too (Menon, 1989). Detailed and rational discussion units of measurements of various kinds like length, weight and volume prevalent in ancient can be seen in *Līlāvatī* written by Bhaskara II (1114-1185 CE) (Panicker, 2006). Measurements are categorized into six in *Samarāṅgaṇasūtradhāra* of Bhoja (c.1040 BCE) which is quoted in *Vāstuvidyā* (VV) is note worthy. *Amarakośa* of Amarasimha (6th Cent. CE) says that measurements are commonly made in three ways, *'tulāṅguliprathai'* meaning, by weight, by length and by volume with weighing balance, measuring scale and by measuring jar (Varier, 2000). Thus it could be inferred that Aṅgula was the basic unit of length commonly adopted everywhere in India (Moothathu, 2008).

Mainly two types of scales were in use. For Vedic Altars, an Anthropometric dimensional system was used based on the height of the chief priest (Yajamāna) who conducts the sacrifice. As altars were not permanent structures the adoption of an anthropometric scale derived from the chief priest will offer perfect serviceability of the structure. On the contrary, the permanent structures needed an absolute scale similar to what is presently used throughout the world. From the etymology of the units used whether in Indian subcontinent or western countries, the nomenclatures are originally derived from the anthropometric terms as evident from Aṅgula, Vyāma which literally means a finger and stretched hand respectively in Sanskrit and a foot, the foot in English. Architect's Data observes,

'Throughout history man has created things to be of service to him using measurements relating to his body. Until relatively recent times, the limbs of humans were the basis of all the units of measurement (Neufert, 2012).

Standardization happened later based on the statistical means considering most possible and the maximum possible values. This is called the *Uttamapuruṣa* (standard person) dimension in Vāstu terminology. Leonardo Da Vinci's famous sketch Vitruvian Man (1490), depicting the proportion of human body has similarities with the above Puruṣapramāṇa.

According to Vedic as well as Vāstu texts, the absolute scale of measurement was derived from the size of an atom. Even in *śūlbasūtras*, the mention of Aṅgula and its subdivisions can be seen (Khadilkar, 2003). All ancient Vāstu texts though the basic unit is derived from the term *paramāṇu* (atom). However certain uniformity is seen in all texts and even *Nāṭyaśāstra* (c.300 BCE) while discussing the design and construction of Nāṭyagṛha, defines Aṅgula in the same way.

aṇū rajaśca vālaśca likṣā yūkā yavastathā |
aṅgulaṃ tathā hasto daṇḍaścaiva prakīrtitaḥ ||

Literal translation: *The sub divisions of Angula are Yava, Yuka, Liksha, Vala, Raja, Anu from Angula Hasta and Danda are also derived.*

All Vāstu texts have also given the same relation and nomenclature for subdivisions. Moreover, *Nāṭyaśāstra* is only quoting the verse from the ancient Vāstu text *Mayamata*. *Mānasāra* has also quoted the same verse. *Viśvakarmavāstuśāstram* has stated that Aṅgula has its origin in paramāṇu and the same subdivision is followed. Thus, Vāstu texts hold the view that an Aṅgula is made up of 262144 atoms when linearly placed.

Table 2.1 Subdivisions of aṅgula according to Vāstu texts

Unit	Higher unit	Unit in terms of paramāṇu
8 Paramāṇu	1 Trasareṇu	8
8 Trasareṇu	1 Vālagram	8^2
8 Vālagram	1 Likṣā	8^3
8 Likṣā	1 Yūka	8^4
8 Yūka	1 Yava	8^5
8 Yava	1 Aṅgulam	8^6

According to *Markaṇḍeyapurāṇa*, all the subdivisions of Aṅgula are multiples of 10 and are given below (Moosad, 1980).

Table 2.2 Subdivisions of Aṅgula in non-Vāstu texts

Unit	Higher unit	Unit in terms of paramanu
10 Paramāṇu	1 parasūkṣmāṇu	10
10 Parasūkṣmāṇu	1 Trasareṇu	10^2
10 Trasareṇu	1 Mahārajas	10^3
10 Mahārajas	1 Vālagra	10^4
10 Valagra	1 Likṣā	10^5
10 Likṣā	1 Yūka	10^6
10 Yūka	1 Yovodara	10^7
10 Yavodara	1 Yava	10^8
10 Yava	1 Aṅgula	10^9

As this study is confined to Kerala region, the accepted Aṅgula is exactly 300 mm and all practitioners follow this value. As there are many variants of scale as per Vāstu, depending on the number of Aṅgulas in a Hasta, the Hasta followed in Kerala is Kiṣku.

Śilparatna of Srikumara (1635) says "*Kiṣku sarvatra sammata"*. It means Kiṣku is accepted everywhere and by everyone. The length of "Indus Inch" (Sykorova, 2006) is 33.5 mm and each unit is further divided into 10 (decimal) that too with high precision. Here the length is roughly matching with what is followed in Kerala i.e. 300mm and dividing in to tens was also not uncommon as in *Viṣṇupurāṇa*, *Markaṇḍeyapurāṇa* etc.

In the modern metrology, definition as well as calibration are equally important. The concept of calibration and a conscious effort to popularize the standard units and measurement could be seen in attempts made by carving the adopted scale in the basements of certain temples. Such calibrations are seen in temples like Panniyur (Panniyur Varaha moorthy temple) near Kuttipuram, Parthasarathi temple at Aranmula and Sri Padmanabha Swamy Temple at Trivandrum. The calibration available in Panniyur temple is supposed to have been engraved by the legendary master craftsman, Perunthachan (c.400 CE).

8 Paramāṇu= 1 Trasareṇu; 8 Trasareṇu=1 Valagra; 8 Valagra= I yuka; 8 yuka=1 Tila; 8 Tila=1 Yava; 8 Yava= 1 Aṅgula and 12 Aṅgula makes a Vitasthi and 2 Vitasthi= 1 Hasta, 4 Hasta= 1 Daṇḍu, 8000 Daṇḍu = I Yojana. As per Kerala Aṅgulimānam (30mm), Yojana will work out to 23.04 Km. The value equivalent to 8 km given in *Āryabhaṭīyam* (499 CE) does not match with this value. However, since the scale

used for construction which is carved at least in some places, helps us to calibrate the scale and use it correctly when the process of rehabilitation, reconstruction or extension of traditional buildings are necessary.

2.1.2 Concept of Vastu purusha

The most important element in the design principle of *Vāstu* is the concept of *Vāstupuruṣa* and *Vāstupuruṣamaṇḍala*. From an Engineering perspective, this could be perceived as a planning tool to develop the layout of the building as well as rooms.

The principle of dividing the entire plot into four as *Khaṇḍas* (quadrants), and then dividing *iṣṭakhaṇḍa* (selected quadrant) into *pādas* (usually 8×8, 9×9 or 10×10 cells) and merging the annular pads to form vīthis (pathways) and drawing the diagonals and other vital lines to find the *marmas* (vital)points are essentialities in Vāstu, both from a point of view of planning principle and from a ritualistic perspective. For some of these principles like placement of columns etc. in *marma* points, it is difficult to figure out the science behind the taboos.

The concept of Vāstu purusha is one of the prime components that connect Vastuvidya to the Vedic religion and rituals. Similarly, the determination of 'ṣaḍvarga' is another component that connects Vāstu tradition with Astrology. Thus, when these two aspects are kept aside as a part of belief system, Vāstu tradition is like any other alternate system of learning which is mostly irreligious in its content and applicable universally.

Vāstupuruṣa is conceived as an asura fitting into each parcel under consideration with his head pointing towards N-E. As it appears, it could be a personified shape of magnetic field connected with Earth-Sun connectivity and Vāstupuruṣa-Maṇḍala is plot of stress contour lines evident from the colour scheme specified for each pāda. Unless and until it is proved scientifically, further deliberation on this is out of place in this study.

Pādas are the divisions of each parcel into 64, 81 or 100 pādas and deities are attributed to each pāda. In a theoretical point of view, these pādas can be conceived as a graphical division for enabling the planning of the building and the room layout. In this context, it may be recalled that Le Corbusier, the famous French Architect incorporated Vāstupuruṣa-Maṇḍala concept in Chandigarh City planning.

2.1.3 Āyādiṣaḍvarga

Āyādiṣaḍvarga are the six attributes that a building or room possesses based on its perimeter. However whether to choose the perimeter or the area as the prime characteristic factor was a debate in Vāstu (MC 3:35). Finally perimeter was accepted particularly in Kerala region and is now meticulously followed. Though this has been mentioned in *Mayamata* (c.300 BCE), strict adherence to this may be later development which occurred parallel to Astrology. Even in 6th text *Bṛhatsaṁhita*, the concept not seen to have considered. But in *Samarāṅkaṇasūtradhāra* of Bhoja in 11th century has stated clearly about it (Agrawala, 1966). Now in Vāstu practice Āyādiṣaḍvarga is the most essential and important consideration.

In modern practice, a building or a room generally conceived in terms of area and rough cost estimate etc. is taken on the basis of area. On a detailed analysis, it could be seen that perimeter as well as area are equally important as far as cost, material usage etc. are concerned. The perimeter is locally called *'chuttu'*. The outcome of 'Āyādiṣaḍvarga' on this perimeter determines its acceptability and hence it is considered as critical parameter in belief system. When the whole building is considered, the 'external *perimeter'* and for individual rooms the 'inside *perimeter'* is taken for 'Āyādiṣaḍvarga analysis' after measuring the relevant perimeters in Hastas (Kol in Malayalam) and Aṅgulas (Viral in Malayalam) units (Neelakantanasari, 1987).

2.2 SUPERSTRUCTURE

2.2.1 Structural Systems in Traditional Architecture

Basically, traditional buildings of Kerala comprise of columns supported on firm base and wall plates or beams supported by the columns and slopped roof supported on to it. The column base supported on firm bed, formed on well compacted earth/firm rock forms the foundation. Structural system mainly consists of columns, its base and column capital beams/ wall plates, rafters, ridge piece and reapers. Of these, the column base and columns are generally made of wood, solid rock or well-built masonry. The roof support is essentially wooden frame work with rafters, ridge piece, battens (reaper) etc. made of hard wood. The roof elements are mostly timber construction and rarely solid rock cut panels.

Rules for sizing column bases, columns, column heads, beams, wall plates, rafters, ridges and reaper are given in *Manuṣyālaya Candrikā*, *Śilpiratna*, *Vāstuvidyā* etc.. When span of the room is large, there was system of providing tie and providing an additional wall plate called Ārūḍhottara. The principle behind this is same as that of truss. The Ārūḍhottara will reduce the span of rafters by providing an additional support. These details are dealt with in all most all primary texts.

Vāstuvidyā mentions in detail about various joints in wooden members. This exhaustedly dealt in *Śilparatna* also. The location of the joints proposed calls of detailed analysis and study as it is very important from structural point of view.

In the 14th Cent. text *Vāstuvidyā* of anonymous authorship there is a chapter called 'Mānalekhana' which exclusively deals with the graphical method of determining lengths of rafters etc. (Cheruvally, 2007).

While mentioning about the height restriction of tall buildings the Silparatna, the effect of wind etc. are mentioned. There are mentioning regarding maximum width also in *Mayamata* (300BCE). In *Bṛhatsaṃhitā* there is an exclusive chapter on earthquake. More over traditional buildings have inherent resistant to earthquake forces owing to its design features.

2.3 SPECIAL STRUCTURES IN VĀSTU

Nāṭyagṛha, Prāsādas, Gopura, Dhvajastambhas etc. are mainly the special structures which require detailed study. Of these Nāṭyagṛha or theatre structures, has uniqueness. In Kerala, there exists, Koothamblalam functionally same as Nāṭyagṛha but differs from Bharata's concept in many aspects.

Bharata has dedicated a chapter in *Nāṭyaśāstra*, one of the most ancient texts in the world on dramaturgy to the design and construction of Nāṭyagṛha or theatre structures. One chapter (Chapter 2) about four hundred verses are devoted for this topic. Later date, due to the unfamiliarity of the subject matter since it being a building science portfolio, most of the commentators who are from the field of theatre, poetry have left much room for confusion in their commentaries. One of the splendid commentaries on *Nāṭyaśāstra* is *Abhnavabhāratī* by Abhinavagupta (c. 950-1016 CE), a dramatist, poet and exegete from Kashmir. In modern period many translations have also done referring to original text and commentaries. One of such scholarly work is available in Malayalam too (Pisharody, 1990). However, because of the distinct nature of the subject dealt with in second chapter in *Nāṭyaśāstra*, the explanations provided sometimes lack clarity and contain some contradicting views. Since the second chapter is exclusively on an engineering topic that too prevailed at least 2000 years back and attempt is made here to conclusively interpret all relevant verses in the order that followed in the text. Certain verses are left out since they are not directly connected with design and engineering of theaters. From the contents it is very clear that Bharata has followed the Vāstuśāstra for the basic design and has incorporated certain special requirements which any theatre structure warrants.

Bharata's *Nāṭyaśāstra* is probably the world's oldest comprehensive text on theatre. Though, the historians have varied opinion about the exact date of *Nāṭyaśāstra*, it is known that it is more than 2500 years old. It encompasses theatre, dance and music; in Indian context these three are inseparable for any stage performance. It's incredibly wide horizon of scope, virtually covers every aspect of stagecraft. The most acclaimed commentary on the *Nāṭyaśāstra* is *Abhnavabhāratī* by Abhinavagupta. As mentioned above, while covering each and every aspect of the theatre in length and breadth in thirty-six (36) chapters, *Nāṭyaśāstra* even has focused the construction of theatre (structure). The Chapter 2 deals with the topic in the most scientific manner. Nearly one hundred verses (400 lines) are devoted for this section in the *Nāṭyaśāstra*.

Kerala is the one and the only state that has preserved the rich tradition of Sanskrit theatre in the form of 'Koodiyattam'. For enacting Koodiyattam, there are special theatre-structures known as 'Koothambalam' in many temples of Kerala. The Koothambalams of Irinjalakuda Temple, Vadakkumathan Temple, Kidangoor Temple etc. are noteworthy among them. The architecture of Koothambalm is exceptional.

Bharata has proposed design rules for the Nāṭyagṛha or Theatre not only considering the mere construction aspects but also the acoustics of auditoria (Rajasekhar, 2000). Music also forms an integral part of Vedic corpus in the name of '*Gāndharvaveda'*. In south India musicology had developed to unimaginable heights and the influence of the same can be seen in the 'musical pillars' in which architecture and acoustics are blended together. The physics of musical pillars is being researched scientifically. A brief account is given below.

'*Musical pillars in south India are very fascinating and found in 16 ancient temples (Madurai, Kancheepuram, Suchendram etc.) in Tamil Nadu, four temples in Andhra Pradesh (Tirupati, Vishakapatnam etc.), one in Kerala (Sreepadmanabhaswamy Temple) and five in Karnataka (Hampi, Chowdeswari etc.) The Pillars are of two types either beating or blowing. The beating pillars, by tapping on them with fingers while the blowing pillars will generate a sound by blowing air in the holes like wind instruments. Usually these pillars are three to seven feet long and are of circular cross sections. Some pillars are also of square, rectangular, octagon and polygonal* *cross sections. Most of these pillars are plain without any carvings but some of the pillars have carvings. These musical pillars are generally classified into three types; 1. Shruti, 2. Gana and 3. Laya. The Shruti pillars when tapped with fingers would produce the basic notes of the swaras (sa, ri, ga, ma, pa, dha, ni) on the basis of which chants would be rendered. By tapping Gana type pillars notes that make classical ragas like Kharaharapriya are produced. Laya pillars would produce a taal (beats) when tapped. Some musical pillars not only produce sounds but also cause adjacent pillars to vibrate in resonance to produce harmonics and create musical effects'* (Prasad and Rajavel, 2013).

It is said that stones which can produce a long, deep sound like that of a bell are known as 'male stones', the stones which have a long vibration like that of a brass vessel are called 'female stones' and the stones that are crude and uneven, with little resonance, are called 'neutral stones'. These types of stones are used to make musical pillars. The sculptors select the rock (stone) to make these pillars by tapping them (Prasad and Rajavel, 2013).

The sizing of theatre structures and its connection with the modern dimensioning principles, the mentioning of Acoustics, methods to prevent echo, increase reverberation time etc. calls for a detailed engineering study.

In the *Nāṭyaśāstra*, though three types of theatre structures are specified only the rectangle theatre and the square theatre are elaborately described. The triangular theatre is just mentioned and some minor details are only given. Available literature is also silent or minimal regarding triangular theatre.

2.4 SUSTAINABILITY AND ENVIRONMENT IN VĀSTU

Thoughts on sustainability that have been embedded in Vāstu are found discussed in a booklet Rational Vāstu, The Science of Sustainability (Mehta, 2005). *Ṛgveda* (c.1500 BC) the oldest available book of the mankind, proclaim forest as mother of all living beings. In epics several mentions could be seen (Sunadareswaran, 2014) in Vāstu the concern and care for environment is its integral part. '*The main concept of Vāstu Sastra is to facilitate a harmonious relationship between human beings and the environment, which leads to sustainable development'* (Patra, 2016).

2.5 RESEARCH STUDIES ON VASTUVIDYA.

Ongoing through the available studies and research works, it could be inferred that as cited previously, scientific studies on the subject are recent. One of the most outstanding and bold steps taken related to subject was the establishment of Vāstu Vidya Prathistan led by Professor Achutan and Professor Balagopala Prabhu. The Prathistan has made a land mark publication 'Engineering Commentary on Manuṣyālaya Candrikā' (1999). Vastuvidya department was established in Sree Sankaracharya University in the year 1996 which also undertook many studies in this regard and has done a few research works too. The Sanskrit departments of other universities also have undertaken research works on some Vastuvidya texts. The common feature of these research works is that the work is done mostly specific texts viewing them under the category of 'Technical Literature' in Sanskrit and mostly done by Sanskrit scholars and thus scientific and engineering aspects are not focused properly. The exception to this are a few research works that were done in SSUS Kalady, but the content of scientific and engineering analysis is very minimal. Only a very few research studies have come out highlighting the engineering and scientific aspects. Among these research works, *Study of Traditional Architectural forms in Malabar Coast*, University of Calicut (Ashalatha, 1994), *A Study on Building Martials According to Vāstuśāstra*, Sree Sankaracharya University of Sanskrit, Kalady (Lal, 1999), *Indian Mathematics Related to Architecture and Other Areas with Special Reference to Kerala*, Cochin University of Science and Technology (Ramakrishnan, 1998), *A Critical Study of Structural Spaces and Built Forms of Kerala Temple and Kovils with Special Reference to Apsidal Forms*, Sree Sankaracharya University of Sanskrit, Kalady, (Vamanan, 2009) etc. are worth mentioning.

2.6 OTHER TEXTS USED FOR THIS STUDY

For this study the understanding of various terminologies, techniques, rules and practices, to the extent possible primary sources are referred to. Referring to the primary sources help to interpret and form an independent view. For the clear understanding of the subject matter, various interpretations of the primary texts in Malayalam and English are found useful.

For clearly understanding the Vastuvidya, knowledge of Indian Texts on allied subjects like Mathematics, Astronomy etc. are also essential. To enable this accomplished traditional text on Mathematics and Astronomy *Śūlbasūtras*, *Āryabhaṭīyam* (499 CE), *Līlāvatī* (1150), *Tantrasaṅgraham* (1500 CE), *Yuktibhāṣa* (c.1530 CE) are also referred to. Malayalam translations of Vāstu texts and independent works like *Vāstukaumudi* (Vasuachary, 1987), *Taccuśāstram* (1980), *Śilpiratna samuccayam* (Vasuachary, 2002), *and Jalaparijñānam* (1999) are also found useful while interpreting original texts. Also, for historical references and for some data the books like *Kṣetra Vijñāna Kośam* (Rajendran,2000) is an encyclopedic work on Kerala temples and data regarding shape and size are also available in this book. *Bhāratīya gaṇitam* (Menon, 1989) and *Prācīnagaṇitam Malayālathil* (Moosad, 1980) have chapters on measurements which deal exhaustively on traditional metrology. *Kerala Sāhitya Caritram* (Ulloor, 1990), *Keralīya Samskṛta Sāhitya Caritram* (Vadakkumkoor, 1962) are found useful in analyzing texts from a historical perspective and fixing the dates of traditional reference texts.

CHAPTER 3

PLANNING AND DEVELOPMENT IN VĀSTU

3.1 INTRODUCTION

Planning in Vāstu tradition and in modern project engineering is very much similar in its contents and approach. The current practice of any building design briefly involves the following activities. The first and the foremost activity is the site selection and then planning the building footprint according to the functional requirements and locating the building in a most desirable location. The internal planning and fixing the room locations and its dimensions follows the above. In Vāstu texts also, the same sequence is followed and its details are examined in the context of current engineering practices.

- Site selection
- Fixing the building location
- Internal Planning

Regarding site selection, Vāstu tradition holds rigorous rules and invariably looks for an ideal rectangular plot located in fairly firm and flat terrain with gentle slope in an environmentally conducive atmosphere ensuring comfort living. While locating the building also, Vāstu canons ensure room for future expansion in the plot and to minimize wastage and better utilization of the entire land. Even the locations of the adjacent buildings that exist, do matter for Vāstu. The other important aspect which Vāstu considers is the 'Aspect' of the building itself. The aspect means, the facing of the building, which Vāstu prefers in either east facing or north facing and that too oriented in the true cardinal direction. Regarding internal planning also there are favorite positions for living rooms, dining rooms, bed rooms, kitchen etc.. Also, there are norms for fixing the ratio of length to breadth while preferring slightly rectangular rooms instead of square ones. As any engineering endeavor needs units for measurements, Vāstu has also its own metrology which is religiously followed once design is concluded. A proper metrology was also in place in Vāstu tradition and its features and peculiarities are discussed initially before moving on to site selection and planning.

3.2 METROLOGY IN VASTUVIDYA

In the modern age, whether it is Science or Arts; Technology or Management, all are ultimately dependent on measurements for quantitative assessment. The need for a measuring system is well said in all Vāstu texts, '*na mānena vinā yukti*' (*no rationale without measurement*) etc.. Well-defined units and scales existed in India from ancient times as evident from Vedic texts and its appendices like Sulba Sutras (Khadilkar, 2003). Vāstu texts like *Mānasāra* (c.400 CE), *Vāstuvidyā* (c.1450 CE), *Mayamata* (c.300B CE), *Viśvakarmīyam* (c.400 CE) etc. have properly defined and stated the need for a measurement system. It is interesting to note that as per all Vāstu texts as well as mathematics texts, the basic dimension is the size of an atom and units of length are derived from it (Cheruvally, 2007). Then the natural question is whether just a mention as 'size of an atom' makes any sense as there are many atoms depending on the element under consideration.

Modern atomic theory commences with the works of John Dalton. (1766-1844). Avogadro (1776-1856) also postulated that equal number of molecules exist in equal volume of any gas under same physical conditions. Extending this, according to modern physics nearly 10^8 atoms could place aside linearly in a centimeter, irrespective of the fact that whether this is a hydrogen atom or a lead atom. In other words, size does not vary considerably but molecular weight varies for each element. Kaṇāda in his *Vaiśeṣikasūtra* (c.200-600 BCE) had postulated that matter is made up of 'atoms' in philosophical context. Regarding the unit measurement, the Aṅgula, though varied definitions and are available in different texts, all of them agree that it derives from the size of an atom. But length of an Aṅgula seems to vary from place to place and period to period. Or in other words how many atoms will fit into an Aṅgula has different answers in different texts as cited in the Chapter 2. Of these, the definition in the text *Lailitavistāra* (100B CE) surprisingly coincides with modern value. It says that an Aṅgula is made of 282475249 atoms (Moosad, 1980). As mentioned earlier, an Aṅgula is 3cm as followed in Kerala. Then size of the atom is $3 \div 282475249 = 1.06 \times 10^{-8}$ and hence the variation from modern value is 6% only as the modern value is also approximately 10^{-8} atoms. Moreover, even if it is a smart guess, the aspiring precision level in the remote past deserves appreciation.

The words, *nellita (*width of a grain*), ellita* (width of a sesame seed), *noolita* (width of a thread) etc. that are very commonly used in local parlance have originated from the Vāstu which are equivalent to Yava, the 1/8th of an Aṅgula and Tila, the 1/64th of an Aṅgula respectively. According to all Vāstu texts, the Paramāṇu is invisible (*paramāṇuritiproktā yogīnām dṛṣṭigocaraḥ*) and the visible sub-division of Aṅgula is

Trasareṇu which is the size of a moving dust particle that could be seen moving chaotic in a beam of sun light (usually which enters in to a room through a small slit). The sub-divisions of the Aṅgula according to Vāstu texts are, Yava (1/8), Tila ($1/8^2$), Likṣā ($1/8^3$), Romāgra ($1/8^4$) and Trasareṇu ($1/8^5$). According to Vāstu, the Trasareṇu, is the smallest particle that a human eye can detect. Trasareṇu is 1/8th of a Romāgra. The Romāgra means tip of a hair. The hair size varies from 17 to 80 microns and hence for the tip of the hair, the value of 8 microns is acceptable. Thus, the size of a Trasareṇu will work out as follows.

$$\frac{30}{8^5} = \frac{30}{32768} = 9.1\times10^{-4} \approx 10^{-3}\,mm = 1\mu m$$

The smallest dust particle that a human naked eye can detect is also the same as above.

12 Aṅgulas (A) make a Vitasthi and 2 Vitasthis make a Hasta (H), muzhakol in Malayalam. As there are eight variants of Hastas as per Vāstu depending on the number of Aṅgulas in a Hasta, the various Hastas are Kiṣku (24), Prajāpatya (25), Dhanurmuṣṭi (26), Dhanurgraha (27), Prācya (28), Vaideha (29) Vaipulya (30) and Prakīrṇa (31). The Hasta followed in Kerala is Kiṣku. According to *Śilpiratna* of Srikumara (1635) '*kiṣku sarvatra sammatā*' meaning Kiṣku is accepted everywhere and by everyone. Incidentally the length of this Aṅgula is more or less matching with that of an *"Indus Inch",* (Sykorova, 2006). The division of Indus scale clearly indicates one unit of measurement of 1.32 inches (3.35 centimeters). Thus, there is a need and scope for further study on Indus Architecture and Vastuvidya tradition. Moreover, the decimal subdivisions of Aṅgula similar to what is seen in Indus scale

has been mentioned in *Mārkaṇḍeyapurāṇa* (200 BCE) as 10 Yava makes an Aṅgula and all subdivisions of Yava are in decimal as 10 Paramāṇu = 1 Parasūkshmāṇu and so on and finally 10^8 Paramāṇu (Atom size) = 1 Aṅgula.

In the modern metrology, definition as well as calibration are equally important. The concept of calibration and a conscious effort to popularize the standard units and measurement could be seen in attempts made by carving the adopted scale in the basements of certain temples. In temples like Panniyur (PanniyurVarahaMoorthy Temple) near Kuttipuram, Parthsarathi at Aranmula, and Sri Padmanabhaswamy Temple Trivandrum, such scales carved for future calibration are seen. The standard scale in Panniyur temple is said to be engraved by the legendary master craftsman, Perumthachan (c.400 BCE).

Adopting such different scales, it could be presumed that the length of the Hasta will increase from 72 cm to 93 cm, probably when these different Hastas might have been divided again in to 24 equal sub-divisions only. Otherwise dividing 72 cm Hasta into 24, 25 etc. This will effectively make each Aṅgula as 3, 2.88, 2.76, 2.67, 2.57, 2.48, 2.4 and 2.32 cm. This will substantiate the existence of variants in the scale. On analyzing the meaning of the names assigned to each type of Hasta, etymologically it could be connected very well with the purpose of the use specified from an engineering perspective. The purpose of each Hasta is given in SR. The names given to each, call for a detailed analysis. Kiṣku is an all-purpose measuring rod consisting of 24 Aṅgulas, but following three, Prājāpatyam, Dhanurmuṣṭi and Dhanurgraha are meant for short, medium and long distance and that too in land survey.

In surveying the need for a curvature correction was identified only in17th cent. Dutch mathematician W.Snellius introduced the systematic use of triangulation in modern survey in 1615 CE. He also showed how planar formulae could be corrected to allow for the curvature of the curve. During this period only plane survey and geodetic survey were differentiated. It was established that Euclidian geometry is not enough for surveying as long distances involves spherical trigonometry as measurements are on an approximate spherical surface of earth (Punmia, 1994).

The Vāstu tradition years back has rightly formulated the measuring system in such a way that the curvature correction could be compensated by adopting a self-corrected measuring rod. For long distance measurement Hasta to be used is *Dhānurgṛha*, (Achyutan and Prabhu, 1998). The very nomenclature of this Hasta as *Dhānurgṛha* literally means that 'that which absorb (compensate or nullify) the curvature. In this for the short distances Prājāpatyam, medium distance Dhanurmuṣṭi and for long distance Dhānurgṛha from this it could be inferred that for land survey proportionately to the distance different measuring rods are proposed which is 25, 26 and 27 Aṅgula long. Instead of applying a correction after measuring, this technique of using a modified measuring rod will produce corrected results. The approach has ingenuity and rationality. Command over spherical trigonometry of Indian mathematicians is evident from the ten spherical problems discussed in *Tantrasaṅgraha* of Nilakaṇṭha (b.1444 CE), in the context of solving astronomical problems (Sharma, 1977). The distance between two points on surface of earth is called 'orthodormic' distance or great circle distance and not the Euclidian distance which is in simple terms, comparable with an ordinary1 Mile (5,280 ft.) and 1 Nautical Mile (6076.115 ft.).

The quality consciousness in measurements can be seen in the descriptions regarding careful making of the measuring threads are proposed in ancient texts and necessity of vigilant taking of reading is also insisted as a canon as depicted in verses 22-25, Chapter 2: *Nāṭyaśāstra* (Rajasekhar, 2000).

As mentioned earlier, in Vāstu texts the units are not divided into multiples of tens (decimal), but as divisions of 8 and in turn multiple of 2. The antiquity of Vāstu texts could be clearly conjectured from this and concluded that early Vāstu texts form the part of Vedic corpus and some of the texts predate even the Puranic era as *Mārkaṇḍeyapurāṇa* (c.200 BCE) specifies a decimal division as mentioned above. The base 2 model of scale can be considered as easiest scaling model humans can conceive as it involves only continued doubling of a given length or continued dividing it to halves. This may be the probable reason why 8 have been adopted as base for sub divisions of Aṅgula. Finally, 12 Aṅgula divisions make a Vitasthi has got similitude with 12 inch forming one foot. This needs an investigation regarding the origin of the Foot in Europe as an Inch which is equal to 2.54 cm also could be fitted into a Madhyama Aṅgula (Medium Aṅgula). As in the case of languages, the Indo-European relationship found by Jones William (1675-1749), there could be a common origin for the metrology also.

Drawing is the language of modern Engineering. Concept of drawing to a scale and finding the unknown lengths was also prevalent in previous days as it is done now. For determining slant lengths of rafters etc., the practice of drawing it to scale was common. The making of slots perfectly in the rafters for collar pins, when rafters are laid in a circular pattern etc., calls for precision and perfection. This was mostly achieved by drawing to scale locally known as 'totu'. In the absence of paper in olden days, sketches required for calculation purpose were mostly drawn in sand spread on a plank or a floor. On the other hand, where sketches or drawings are required to take out measurements, these were drawn on wooden planks over wooden pieces with chisel. While drawings are made, the convention was top East in contrary to the modern convention of top North. Method of determination of slant lengths of Vikṛtilūpa using the graphical method is given in *Śilparatna*. These Vikṛtilūpa are the slant rafters starting from the two ends of ridge-piece and resting on the wall plates on shorter sides in a radial manner. Thus, each Vikṛtilūpa are three dimensional.

Thus, it can be seen that the concept of drawing to scale were well understood in ancient India and it was followed for the building design in a scientific manner. The graphical method of determination of unknown lengths was also common.

caturaṅgulato vibhajetvikṛtilūpāpaṅktisaṃkhyakārdhena/
ekaikāṃśavihīneṣvakhitabhujeṣvabdhimātrakam koṭiḥ//(*Śilparatna* 33.3)

Literal Translation: *In a Bhuja (height of a right triangle) of length 4A all Vikṛtilūpas on one side are marked. Then the Koti (base of a right triangle) is also marked with 4A length. Then diagonals are drawn.*

Draw a horizontal line (in wood with chisel) with 4A long and draw a vertical with 4A height. Then mark the locations of slant (Vikṛti) rafters. Then draw diagonals from these points, again draw a horizontal equal to each of the diagonal as base and same vertical as before. Then length of the diagonal will be the length of the Vikṛtilūpa. Mathematically it is prefect as slant length in a three-dimensional system is as first diagonal obtained is $\sqrt{l^2+b^2}$ and final slant length is $\sqrt{l^2+b^2+h^2}$.

This is elaborately discussed in full Chapter in the text *Vāstuvidyā* (15^{th} Cent.) of anonymous authorship, under the title, 'mānalekhana' (Verses 1-52, Chapter 11, *Vāstuvidyā*). The chapter gives the method for determining unknown length for various structural elements and marking them in respective members for cutting (Cheruvally, 2007). The method given in verse 22 and 23 regarding determination of collar pin is given in *Yuktibhāṣā* (c.1530) to demonstrate similar triangles (Rajasekhar, 2009).

3.3 SITE SELECTION

Tradition was very cautious in site selection. It was meticulous in ensuring the availability of all factors favorable for a strong and durable building and all conducive environmental factors needed for a comfortable living. All texts are very particular in specifying the favorable attributes that a site should possess. The unfavorable elements that are to be eliminated are also elaborated. This includes many on-site tests and procedures apart from mere reconnaissance of the site. It included soil strength determination, ground water assessment, previous land use, environmental and climatic conditions including the assessment of flora and fauna and nature of ground (Rao, 1990).

Referring to National Building Code, main clause # 6 speaks on plot selection. Sub clause # 6.1 depicts that '*No building shall be constructed on any site on any part refuse, excreta or other offensive matter'*. The same criteria can be seen in Vāstu texts, for instance, *Mayamata* (300BCE). Land must be devoid of ash, bone, worms, white-ants., clinker, waste, husk, nails, and hair etc.. All these are indicative of a waste disposal yard, probably filled up or earth or earth used as graveyard or funeral ground, hence undesirable for a residential plot.

Under the same main clause, sub clause #6.2 speaks about dampness. So also the *Śilparatna* (1635 CE) explicitly says to avoid damp areas (MC Verse 3. Chapter 3) and *Manuṣyālaya Candrikā* (c.1550) recommends to avoid a plot with central dip (MC Verse 20, Chapter1).

Under the main Clause # 8, Open spaces (within a plot), sub-clause 8.1.3 requires a minimum open space of 1.5 m around the building. Vāstu ensures the concept of leaving *piśācavīthi* (Verse 16, Chapter 2) around the building by restricting the building to a desired quadrant and it will ensure the FAR (Floor Area Ratio) as per Building Rules (Refer Fig. 3.1).

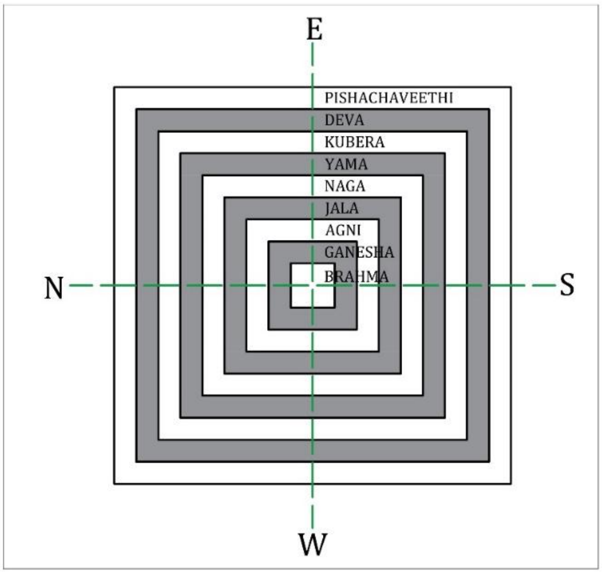


Fig. 3.1 VeedhiVinyasa

Shape of a plot was very important in Vāstu. Rectangular and square plots were always preferred. This helped to achieve maximum utility of available plots and helps to plan the buildings. Orientation was another important aspect in Vāstu planning. As buildings were oriented in cardinal directions, the plots were invariably oriented in these directions which helped a lot in wastage of land in odd shape. Most of the old towns in Kerala attest this.

Five important Acts by the government pertaining to the planning of buildings has been precisely anticipated in *Manuṣyālaya Candrikā* (c.1550 CE) and depicted in a single verse.

The location where houses should not be constructed is given in *Manuṣyālaya Candrikā*.

> vrīhikṣetrādidevālayajaladhinadītāpasāgāragoṣṭha
> grāmādīnāmatīvāntikam upakurutenaikadhā mandireṣu/
> devāgārānnarāṇām atiśubhadaṃ kiñcid ūnaṃ samaṃ vā
> tasmādabhyunnataṃ ca dvitalavidhirayaṃ neṣyate tatsamīpe// MC 1:28

Literal translation: '*No houses shall be constructed to the close proximity of agricultural fields. mountains, religious structures, sea or ocean, rivers, hermitages, farms (cattle etc.); the second stanza says that the buildings proposed near places of worship shall not be double storied or the height of building shall be less than that of the place of worship.*'

Traditionally, most of the towns and villages were developed in around a prominent temple or other monumental structures. These structures are prime and have architectural prominence and archeological relevance as a heritage site. **Town and Country planning Act (2016),** issued by Kerala Govt. has included the places of worship in the zoning act. Residences in the hermitages are also now regulated under zoning act.

Now there are restrictions by law to use paddy fields and wet lands for building purpose. **The Kerala Conservation of Paddy and Wetland Act, 2008,** prohibits the reclamation and controls construction in agricultural fields. The Vāstu also prohibits construction near agricultural lands. Present regulation is to check the shrinkage of agricultural wet lands due to unscrupulous reclamation of land for commercial purposes. In ancient period when land was available in plenty, this restriction might ensure healthy living. Also, fields are mostly clayey and can't offer good bearing strata. Moreover, most of the agricultural lands are low-lying prone to flooding which is desirable for plants as flooding brings lot of fertile slit.

The Kerala Forests Vesting and Management of Ecologically Fragile Lands Act, 2003 prohibits construction near mountains. Though present regulation is to prevent encroachment in to the forest land which is ecologically fragile, in olden days too there were concerns in building residences in close proximity to mountains. Moreover, highlands of Kerala are prone to landslides, *Urulpottal* in local terms due to particular geography of Western Ghats.

Coastal Regulation Zone (CRZ) and Regulating Activities in the CRZ (1986) prohibits all constructions within 500 m of tidal line.

The control of farms comes under **Kerala Panchayath Raj, Licensing of Livestock farms Rules, 2012**. So also houses near cattle farms are forbidden but, of course a cattle shed, one or two cows can be in there near the house.

3.4 PLANNING IN VĀSTU

In the site selection process, tradition insists for a regular rectangular plot. Irregular plots are circular, semicircular, triangles, pentagons, hexagons, trident shaped, trapezium, convex (Tortoise), concave (Fish), with central ridge (Elephant) in shape. If the available plot is not rectangle, it has been advised to set out a regular plot out of the irregular available plot. Then large plots are divided in to quadrants and further quadrants are divided if parcel size is large. This process ensures future expansion provisions and avoids wastage of land.

All Vāstu texts insist on regular plots for any building activity that too oriented in the cardinal direction. In order to avoid the use of irregular and disoriented plots, these texts classify the odd shaped plots under inauspicious category. For this purpose, the process or experiment for determination of the four cardinal directions E-W-N-S is given in these texts which are mostly dealt with under Diknirṇaya or Dikparicheda. The validity of these experiments can be proven mathematically.

The most common method for this is called Śaṅkusthāpana or Indian gnomon method using a wooden peg (above ground height 360 mm) and making its shadows in open ground before and afternoon after drawing a circle around the peg. In this context, it may be noted that magnetic North and Geographical North vary from place to place depending upon the declination (magnetic) of the place. Here the geographical (cardinal) directions are only relevant. After fixing the four cardinal directions, buildings are set out parallel to these directional lines. By setting such rules mandatory it is deemed to act similar to a Building Rules set by the municipalities in modern period. This helps much in proper town planning and helps to bring effective land use and utilization of lands. It prevents the division of lands into irregular geometry.

3.5 TAUTOLOGICAL APPROACH IN FIXING THE ASPECT (FACING) OF THE BUILDINGS IN VĀSTU

As stated above, in Vāstu tradition, placing a building in proper orientation is very important and mandatory. The buildings are placed only in true cardinal directions and are fixed as cited above. According to the above-explained principle of orientation in Vāstu, there are only four options i.e. East, South, West or North as buildings have to orient in the cardinal directions. Then the question is about finding out of the most preferable of the four directions. The preference is given explicitly in the texts. The relevant verse from *Manuṣyālaya Candrikā* (c. 1550) explicitly mentions that North and East facing houses are recommended and widely followed practice in Kerala is to fix facing towards East (Neelakantanasari, 1987).

In any building site (plot), from the aspect of storm water drainage a gentle slope of the proposed land (ground), is always desirable. In Vāstu also it is recommended that a slope in the proposed ground (plot) is desirable and there are also recommendations regarding the desirable slope direction. In this regard reference shall be made to MC.

indrāśādinatāvanītaditarā śādyunnatāṣṭaukramād
govahnyantakabhūtavāriphaṇabhṛmātaṅgadhānyāhvayāḥ/
vīthyo’tra kramaśo’bhivṛddhighanahānyantārthahānipradā
dāridryātmajahā nivittaśubhadāstādṛkkṣilau tasthuṣām// MC 1:19

Literal translation: *These recommendations could be summarized as follows. Ground (Land) on which buildings are proposed must have slope towards North, North-East and East. All other directions of slopes (land gradient) are undesirable. The ground having a specific slope have specific names likes, Govīthi (E), Agnivīthi (S-E), Yamavīthi (S), Bhūtavīthi (S-W), Jalavīthi (W), Nāgavīthi (N-W), Gajavīthi (N), Dhanyavīthi (N-E). Some texts like Vāstuvidyā, have further subdivided into sixteen as shown in Fig. 3.2 (Sastri, 1913).*

Another notable text *Śilparatna* SR 3:31(1635 CE) which is followed widely in Kerala region has stated the same recommendation.

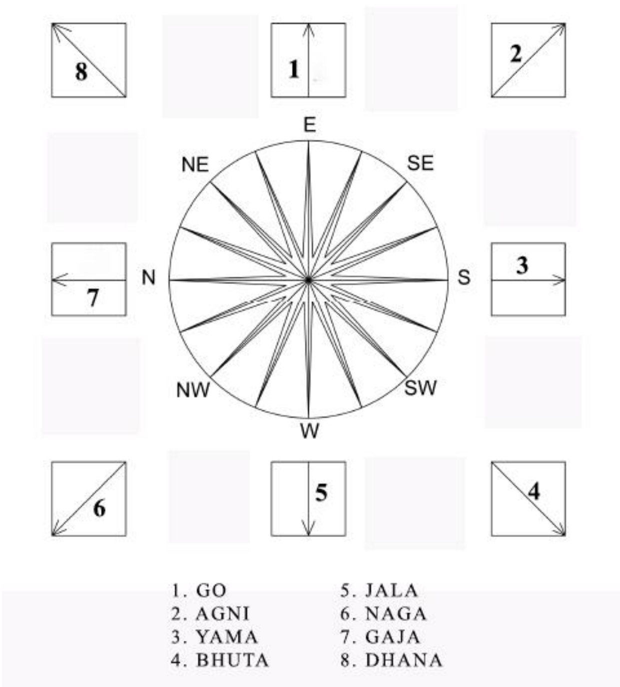


Fig. 3.2 Classification of land according to slope

3.5.1 Truth table of Various Propositions

Let A (p, q, r, s, t, u, v, w) denote the proposition that represent Facing direction in the set of all possible cases given by a sample space S = { E, S-E, S, S-W, W, N-W, N, N-E} where E, S-E, S, S-W, W, N-W, N, N-E represent facing direction in the following cases as shown in Table 3.1 and Table 3.2.

Table 3.1 Facing Directions

Facing Direction							
East (p)	South – East(q)	South (r)	South-West (s)	West (t)	North-West (u)	North (v)	North-East (w)
T	F	F	F	F	F	T	F

Table 3.2 Facing Directions

Facing Direction	**Desirable (P)**	**Undesirable (Q)**
East	1	0
South –East	0	1
South	0	1
South-West	0	1
West	0	1
North-West	0	1
North	1	0
North-East	0	1

B (p, q, r, s, t, u, v, w) denote the proposition that represent Slope towards different direction in the set of all possible cases given by a sample space S = { E, S-E, S, S-W, W, N-W, N, N-E}where E, S-E, S, S-W, W, N-W, N, N-E represent Slope towards various directions in the following cases. Since there are 8 propositional variables, there will be 2^8 (=256) possible cases in the truth table for B (p, q, r, s, t, u, v, w). Only three cases obtained is considered here and only 64 are practically possible. Refer to Table 3.3 and Table 3.4.

Table 3.3 Slope Directions

Slope towards							
East (p)	South – East(q)	South (r)	South-West (s)	West (t)	North-West (u)	North (v)	North-East (w)
T	F	F	F	F	F	T	T

Table 3.4 Slope Directions

Slope (Towards)	**Desirable**	**Undesirable**
E (Govīthi)	1	
S-E (Agnivīthi)		0
S(Yamavīthi)		0
S-W (Bhūtavīthi)		0
W (Jalavīthi)		0
N-W(Nāgavīthi)		0
N(Gajavīthi)	1	
N-E(Dhanyavīthi)	1	

Mathematically only when the conjunction of two propositions A (p, q, r, s, t, u, v, w) and B (p, q, r, s, t, u, v, w) is true when both the propositions are true. Otherwise, it is false. Refer to Table 3.5.

Table 3.5 Facing Directions -Truth table of A (p) ^ B (p)

A(p)	**B(p)**	**A(p)^B(p)**
T	T	T
T	F	F
F	T	F
F	F	F

By definition of Conjunction, A (p) ^B(p) is true when both A(p) and B(p) are true. Similarly, for the propositions A(r) and B(r). For other propositions, for example, consider the truth table of A(r) ^B(r). Refer to Table 3.6.

Table 3.6 Sloping Directions: Truth table of A(r) ^B(r)

A(r)	**B(r)**	**A(r)^B(r)**
T	T	T
T	F	F
F	T	F
F	F	F

Here, it is given that the truth value of A(r) is F and B(r) is F. Therefore, the truth value of A(r) ^ B (r) is F. Similarly, truth values of the conjunction of other possible propositions are given in Table 3.7.

Table 3.7 Facing Directions

A(p)^B(p) East (p)	A(q)^B(q) South – East (q)	A(r) ^B(r) South (r)	A(s) ^B(s) South-West (s)	A(t) ^B(t) West (t)	A(u)^B(u) North-West (u)	A(v)^B(v) North (v)	A(w)^B(w) North-East (w)
T	F	F	F	F	F	T	F

If all the truth values are T in all possible cases of A^ B then A^ B is a tautology. Truth values of A and B for p, q, r, s, t, u, v, w are known. Therefore, consider only the row corresponding to this case only. Here it is true in two cases which are shown in the above truth table. Here Truth value is T in A(p) ^B(p) and A(v) ^B(v). Thus, when above two verses are combined it may be seen that houses facing East and North are only desirable and slope towards these directions are also recommended.

Let us examine different scientific or engineering reasons mostly climatological factors that govern the facing of building and if we prepare the truth table, final recommendations also will merge with the above results.

Hence the analysis of the above aspects of orientation and slope is analyzed with respect to Kerala region which lies between 8°N and 13°N in the Northern hemisphere. Due to the apparent movement of Sun, due to change in the declination, from September 22^{nd} to March 21^{st} the Sun is in the south side and by afternoon southern and western walls get heated up during this period. Since winter in the midland and coastal area of Kerala is very feeble, most of the period is very sunny except a few rainy days during October due to south-east monsoon. Similarly, by June 1^{st} South West monsoon begins and prolongs roughly till September. Thus, most of the sunny days will be between September 22^{nd} and March 21^{st} when the sun is in the southern hemisphere. Hence from the position of the Sun, South and West facing becomes undesirable (Mehta, 2005).

Fig. 3.3 Declination and monsoon progression

3.5.2 Slope of the ground

The Earth-Sun relationship governs the amount of radiation received at a particular point on the Earth's surface. The cosine law which states that the intensity (I) on a tilted surface equals the normal intensity times the cosine of the angle of incidence (Koenigsberger, 1988).

$$I_C = I_B \cos\beta$$

Where I_C the intensity on ground and I_B intensity of incident ray and β is the angle of incidence. Considering this, the desirable slopes to reduce the heat gain on the ground will be a reverse slope (Refer Fig. 3.4). The configuration of solar panels kept in Northern hemisphere itself is an ample proof and solar panels are also tilted according to the latitude of the place. Hence when the sun shines on the southern side, a slope towards North is desirable and also when the sun is in the West, an Eastern slope is desirable to reduce the heat load on the building. As heating of building in afternoon is more detrimental than in the morning in a tropical climate, western facing becomes undesirable (Refer Table 3.8 and Table 3.9).

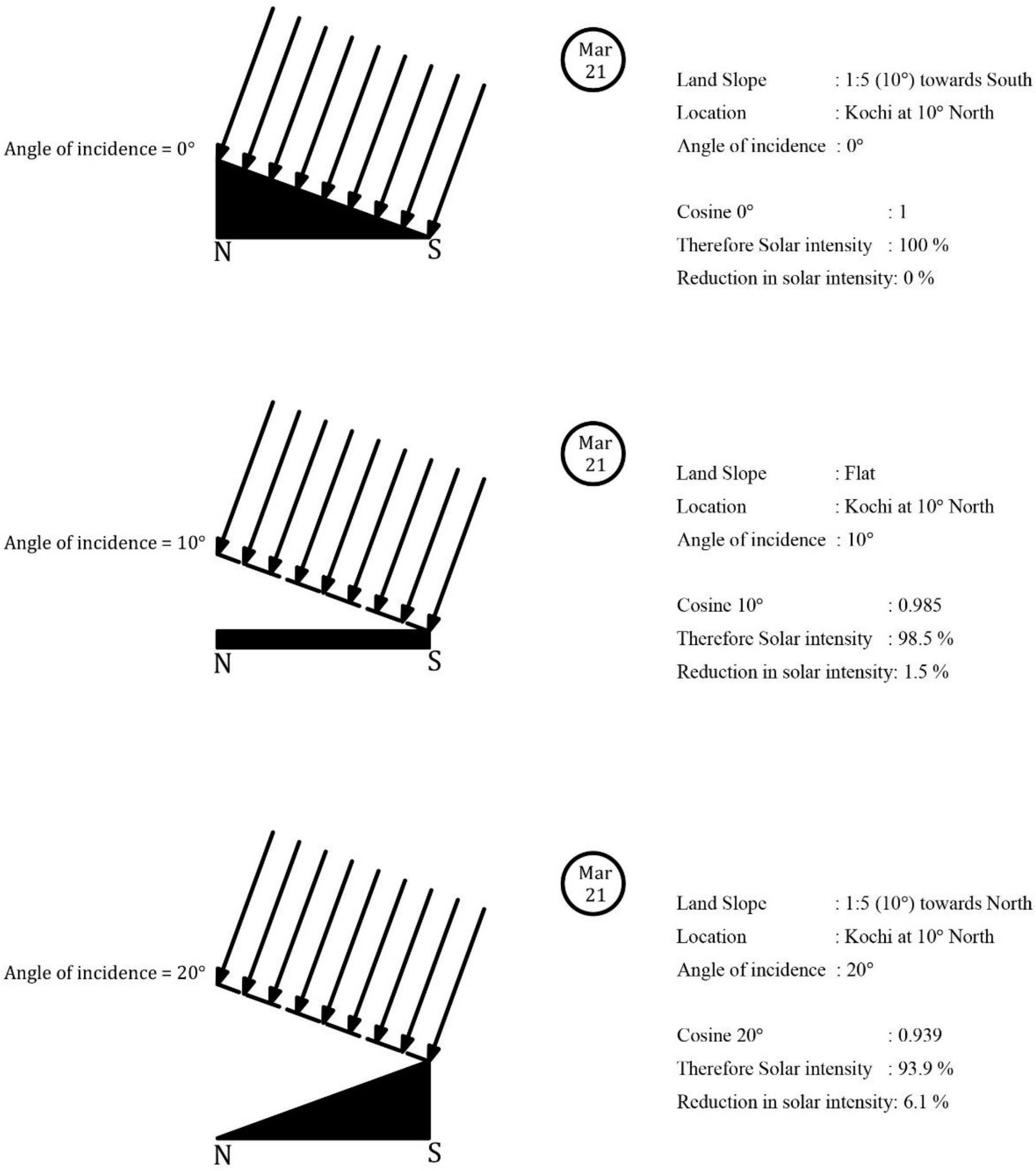


Fig. 3.4 Solar radiation

Table 3.8 Facing Directions depending on Sun’s Path

Facing Direction	**Desirable**	**Undesirable**
East	1	0
South –East	0	1
South	0	1
South-West	0	1
West	0	1
North-West	0	1
North	1	0
North-East	1	0

Table 3.9 Slope of Ground-based on solar Intensity

Slope (Towards)	**Desirable**	**Undesirable**
East	1	
South –East		0
South		0
South-West		0
West		0
North-West		0
North	1	
North-East	1	

Monsoon Protection: In Kerala, monsoon blows from S-W predominantly during S-W Monsoon and sometimes from W and N-W and from S-E during S-E Monsoon. It is advisable to plots sloping from S-W to N-E so that rain will not hit directly during the predominant rainy season. Refer to Table 3.10 and Table 3.11.

Table 3.10 Facing directions depending on Monsoon

Facing Direction	Desirable	Undesirable
East	1	0
South –East	0	1
South	0	1
South-West	0	1
West	0	1
North-West	0	1
North	1	0
North-East	1	0

Table 3.11 Facing Directions - Slope of Ground Monsoon

Slope (Towards)	Desirable	Undesirable
East	1	
South –East		0
South		0
South-West		0
West		0
North-West		0
North	1	
North-East	1	

In the same way, scientifically, we can prepare a truth table considering many other aspects such as storm water drainage, fire progression in case of a fire incident, ground recharge etc.. Once the facing directions are fixed as North or East and ground made to slope in the same directions as recommended in Vāstu, following engineering requirements are concurrently fulfilled as follows.

- Living area and external court yard where day time activities are more will be protected from Sun adding comfort.
- Heat load in the building can be reduced additionally providing less opening in South and west and protecting those sides with chajjas or verandhas.
- Slope on the South/West towards North/East will reduce amount of radiation.
- The menace of S-W monsoon winds will not affect the house as it is not facing to S or W.
- Since the ground is sloping away from N or E, facing towards N or E will ensure storm water drainage away from front yard.
- Sloping of N/E slope will ensure ground water recharge and replenishment (rain water harvesting) of open wells which are usually located in the N-E.

3.6 LOCATION OF BUILDING IN PLOT

As indicated earlier the orientation of buildings in the cardinal direction was a must in traditional architecture. To ensure this most of the ancient villages and towns developed around a centrally placed temple or palace or such important monument building oriented truly in the cardinal direction. Hence all the plots in the traditional buildings were more or less rectangular or square. Over and above all Vāstu texts insists on regular plots for any building activity that too oriented in the cardinal direction. In order to avoid the use of irregular and disoriented plots these texts classify the odd shaped plots under inauspicious category. The verse from *Manuṣyālaya Candrikā* in this aspect is most relevant.

vṛttārdhendunibhātripañcarasakoṇā śūlaśūrpākṛtir
matsyānekapakūrmapṛṣṭhakapilāvaktropamā medinī/
bhasmāṅgāratuṣāsthikeścitivālmīkādibhiḥ
varjyā madhyanatā sagarbhakuharā vistrā vidiksthāpi// MC 1:18

Literal Translation :*circular, semicircular, shapes with three, five, six corners, trident shaped, shape of surpa (Trapezium), convex (Tortoise), concave (Fish), with central ridge, (Elephant), shape that resembles cow's head (Trapezoidal), when ploughed if bone, ash, charcoal, husk, hair, worms etc. are present, land with white-ant hills, central dip, hollow inside, bad (stuffy smell) for the soil, disoriented plots, all these must be avoided.*

From the above, it is clear that only quadrilaterals are acceptable and that too oriented in the proper cardinal directions. In the quadrilateral slight boundary corrections are usually made by inscribing a rectangle fitting into the plot. This is practically done after the determination of the cardinal direction (Diknirṇaya). If an existing temple or well-built residential building exist which was earlier positioned after Diknirṇaya, by taking offsets, the two lines are established at the centre of the plot- the East-West line and North-South line. This plot will be divided into four quadrants which in Vāstu terminology is called Khaṇḍas. The proposed house will be placed in desired Khaṇḍa. The most desired Khaṇḍa is North-East, the order of preference is South-West, North-West and in South–East buildings are not placed and this location is usually used to set up funeral pyres (Refer Fig. 3.5).

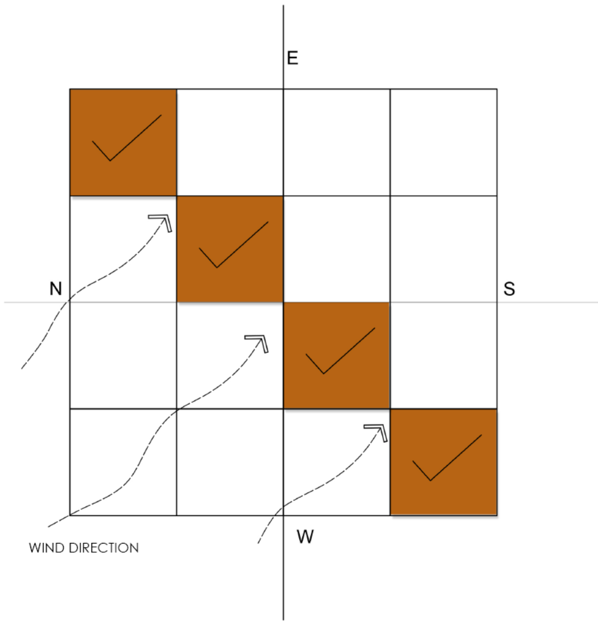


Fig. 3.5 Desirable quadrants and sub divisions

If the plot sizes are bigger, each Khaṇḍa is further divided in to Khaṇḍas as described above till a size suitable for the house is obtained.

This process is one of the key tools in planning as it effectively creates many usable plots from a large plot. Suppose the owner ventures to set up the house at the middle of the plot, the provision for generating future plots will be jeopardized. On the other hand, by rule of dividing the plot in to khaṇḍas and further dividing if plot size is larger makes sense from planning leaving more room better utilization of the land and future expansion provisions. Thus, an element of sustainable philosophy is underlying in the concept of Khaṇḍaparikalpana and is relevant in contemporary situations too.

The instruction to leave the N-W and S-W khaṇḍas free of any building also ensures a free air flow and when funeral pyres are set up, the smokes from such pyres will never enter in to residential houses. More over the prominent wind direction is from N-W (Vāyukon) to S-E (Agnikon). Therefore, leaving these two khaṇḍas vacant has a logical reasoning (Refer Fig. 3.6).

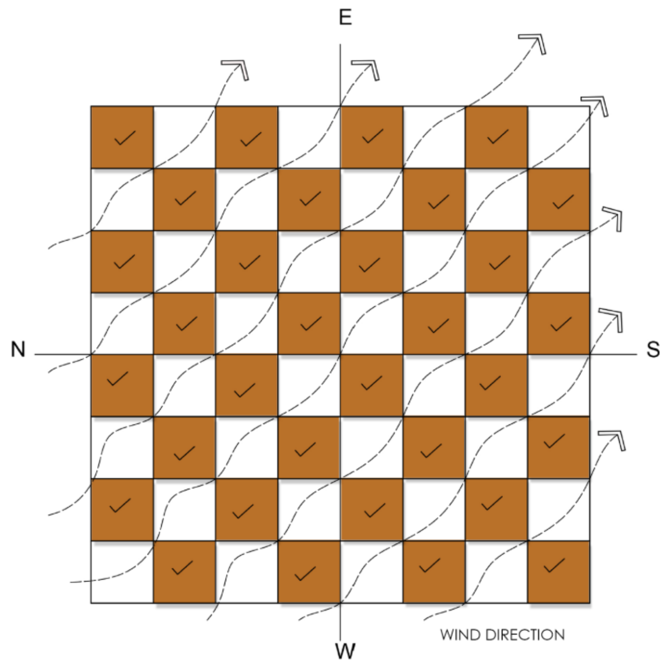


Fig. 3.6 Quadrant divisions

Thus Khaṇḍaparikalpana (Quadrant Layout) is an effective tool in planning which will ensure that all buildings are aligned properly in cardinal directions ensuring effective utilization of land. Moreover, the town planning and road layout can be done effectively. In old towns where town developed around the temples, this type of town planning can be seen. Vaikom town which is developed around the Vaikom Mahadeva temple can be cited a best example. Even now odd plots in the town are a few as all old roads and plots are properly oriented.

3.7 PĀDA VINYĀSA AND VĪTHIPARIKALPANA

After the desired khaṇḍa is selected, the khaṇḍa will be divided in to pādas. This is called Pādavinyāsa the division usually adopted are 8×8× or 9×9 or 10×10, (Verse 11, Chapter 5 Vastu Vidya). The pāda division is similar to a graph paper in modern context. Here instead choosing different scales in graph, graph itself is modified according to the need.

After dividing the desired *Khaṇḍa* or portion of land set aside for building, it will be again divided into in to 64 or 81 or 100 pādas to aid for room lay out finalization. Most of the Vāstu directives for position of rooms are in terms of pādas. For example, the recommended positions of Kitchen are given in *Manuṣyālaya Candrikā* as follows:

> parjanye pācanālayaṃ śikhini vā meṣe vṛṣe vānile
> tatraivāpi ca bhuktasadmamakare cāpāṃpatau ceṣyate/
> kumbhe saukhyagṛhaṃ tathaiva makare vāyau tadāvaśyake
> kartavyaṃ vṛṣameṣayoridam atho vāyau tatholūkhalam// MC 7:35

Literal Translation: *The location of the Kitchen shall be in Parjanyapāda (N-E) or in Agni Pāda (S-E) or in Meṣa (E) or Vṛṣabharāśi (E), or in Vayupāda. (N-W). The dining shall be in the same locations as above or in the Makara rāśi (N) or Varuna Pāda (West).Living room can be Kumbha rāśi (N) or on Makara rāśi (N) or in Vāyu Pāda. (N-W) If required it can be in Vṛṣabha (E) or Meṣarāśi. (E) The shed for rice milling, sieving etc. shall be in the vāyu pāda. (N-W)* (Refer Fig. 3.7).

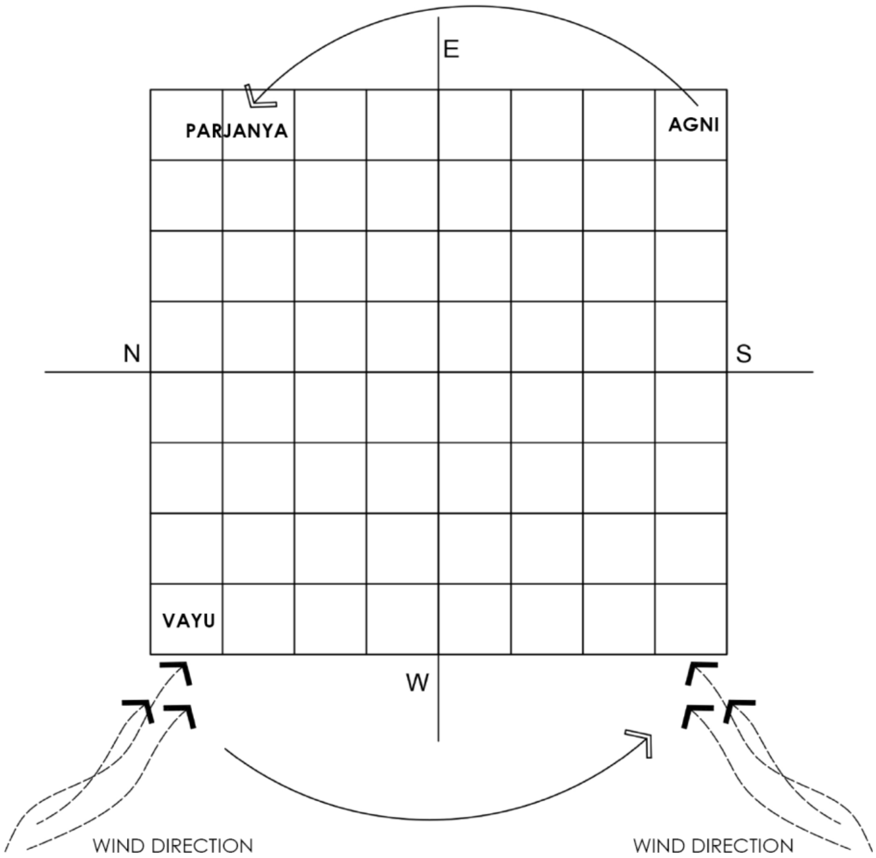


Fig. 3.7 Kitchen location

Here it can be seen that in Kerala usually the Kitchen is located in the *Parjanyapāda* or in the N-E portion. Here it is pertinent to quote *'Parjanyo annadaḥ'* from Bhṛguvalli of *Taittarīyopaniṣad*, But in traditional texts they prefer to have it in Agni pāda. The reason is that in Kerala the predominant wind direction is from S-W during rainy season but traditionally Vāyukon (Wind Corner) is N-W and they specified as S-E. This confirms that that *Manuṣyālaya Candrikā* has modified the location according to Kerala climate. Such a research and development has not happened after the period of *Manuṣyālaya Candrikā* and *Śilparatna* (16-17th Cent.).

When these pādas are merged in an annular fashion it is called vīthi. The central one is called Brahma vīthi and outer most one is called Pisācavīthi, according all Vāstu texts, no building shall encroach into this Pisācavīthi. This matches with modern building code regulations to leave minimum set back.

> nandadvandvapuṭena vā vṛtitayā bāhyādimadhyāntimā
> vīthyaḥ syuḥ paritaḥpiṣācadiviṣadvittādhibhūdaṇdinām/
> nāgāmbvagnivināyakadruhiṇanāmnāṃ cāsu nindyāḥ smṛtāḥ
> paiśācāgnyahidaṇḍināṃ gṛhavidhau vīthyaścaturdikṣvapi// MC 2:16

Literal translation: *When (this site is) divided into 18×18 grid, there are 9 enveloping paths (around its central point). From the outer path to the centre, the paths are those of Pisaca, Deva, Kubera,Yama,Naga,Jala,Agni,Ganesa and Brahman. Here the vithis of Pisaca, Agni, Naga and Yama in all four directions are bad for locating houses.*

The central courtyard shall be at least 144 cm as per Vāstu and minimum dimension of court yard as per National Building Code clause 8.2.5 is 120 cm. Similarly, minimum setback as per Kerala Building Rules, 27(3) is 1.0m. By leaving the outmost vīthi, assuming a plot width of 10.m, the veedhi width will be1.0.

Another aspect is that as New Building codes have special provisions and exceptions for small plots (Chapter 8: KBR). Vāstu texts have also such considerations and are depicted under Alpakṣetravīthi.

> kṣetre'tyalpetu madhye'ṅgaṇamapi ca kṛtāntātmabhūsūtrayogāt
> kiñcimannītvā svagatyāpi ca bhuvanacatuṣkaṃ kṛtaṃdṛśyate/
> atyalpā eva vīthyohyaśubhaśubhaphalānyevam evālparūpā-
> ṇyasmādīśādikhaṇḍādyadhigatanavavīthīvidherneṣyate'tra// MC 2:18

Literal translation: *In some situation, in small sites, the courtyard (ankana) is seen in the centre and the house is seen shifted from the intersection of Brahmasutra and*

Yamasutra with shifts (gamana) prescribed for each (sala).The vithis are very narrow (atyalpa) and similarly the good and bad effects also are small (alpa). Hence the division intp isakhanda, etc. and pisacavithi etc. is not considered here.

As per Vāstu also those who are having small extent of land are exempted from rules.

The Khaṇḍaparikalpana and vīthi restrictions will ensure FAR requirements and set back requirements in all sides. The restriction in outer most vīthi itself will ensure 36 % vacant area all around the building in the quadrant alone. Moreover, a space all-round the building is a must for fire protection point of view and ventilation consideration.

The traditional Nalukettu, in this context, well suits the geography and climate of Kerala considering temperature, humidity, precipitation, driving rain, solar radiation, wind characteristics and vegetation.

Regarding the location of well it is stipulated in Vāstu that it should never be located in Agnikon or S-E corner. (Verse 30, Chapter 7)

> āgneyyāṃ bhavanasya kūpakhananaṃ pūrvaṃ kṛtaṃ yā tathā
> vāpī dāhabhayādikaṃ prakurute tadvat phalaṃ dakṣiṇe/
> grāmāderapi dīrghikādikaticinnecchanti yāmyetathai-
> vārāmo gṛhasannidhau phaṇabhṛtāṃ vāso’pi naiveṣyate// MC 7:30

Literal translation: *If well and similarly tank have been dug in the south-east (agni) of house earlier, it causes fear of fire hazard etc. On south side also similar effect is caused. In the south side of villages etc. tanks etc. are not desirable near the houses. Similarly, gardens and sacred groves are not desirable near the houses.*

As wind in the summer season is predominantly from N-W and hence the in the case of a fire incident the muster (assembly point) must be in the wind ward side i.e. in N-W and access to well in S-E will be difficult as it is on the leeward side.

3.8 ROOM DIMENSIONING AND PROPORTIONS

In architecture, the ratio of length and width plays an important role in giving roominess and fixing functional layout within the room. Architects always prefer a rectangular room than a square one for the above reason. Vāstu texts have classified this ratio and desirable proportions are suggested. Moreover, the linear dimensions are considered as modules of 8A (24 cm) this could be regarded as forerunner of modern 'modular coordination principle' and standardization of various elements in a building. The 'ayādi ṣaḍ-varga' calculation based on Perimeter restricted the random use of dimensions and in a way, it helped for standardization.

Similarly, in design the proportions are very important. From renaissance period, in the west most fascinating ratio in arts as well as in architecture is the 'golden ratio'. Mathematically, when the ratio of two parts is equal to the ratio of the larger part to the whole is same, the ratio is said to be in golden ratio. $\varphi = \frac{a+b}{a} = \frac{a}{b}$

$$\varphi = \frac{1+\sqrt{5}}{2} = 1.61803....$$

In Vāstu tradition this ratio is not seen to be mentioned. More over the for proportioning of the rooms, four classifications are there Samatata, Pādona, Pādādhika and Ardhādhika. Ratio 1: 1 (up to 1.25) Samatata, 1: 1.25 (up to 1.5) is Pādādhika, 1:1.5 (up to 1.75) Ardhādhika and 1: 1.75 (up to 2) Pādona. As per Vāstu tradition the for residential buildings most desirable is Pādādhika (Refer MC:7 Chapter 4). This means that the preference is for the ratio 1: 1.25 to 1:1.5. The golden ratio is in the undesirable range especially for residences according to Vāstu as it lies in the range of 1: 1.5 to 1:1.75 (Ardhādhika). Modern engineering texts also attest Vāstu recommendation rather than Golden ratio in this regard. Rectangular rooms have more roominess than square rooms. Ratio 1.2 to 1.5 is desirable (Arora, 2010).

Here it may be noted that the source of the Golden Ratio, the Fibonacci numbers (1202 CE) and his series (1,1,2,3,5,8,13,21,34,55,89,144 ……) are known to India mathematicians long back at least from 600 CE (Singh, 1985) .

3.9 CONCLUSION

In site selection, planning and development the Vāstu canons and modern code provisions building rule stipulations and guide lines have many parallels and commonalities. Based on Australian guidelines on Climatic design, '*The passive design issues, which should be considered during the design process to ensure an optimum thermal design include: site layout and orientation, Planning, sun control, air movement and wind shelter and thermal capacity of construction* (Caitlin, 2013). All these aspects are duly considered in Vāstu design also. Similarly, the design principles cited in Manual of tropical housing and building also matches with Vāstu principles (Koenigsberger, 1988).

To conclude from the comparisons done with Modern Building Codes and Vāstu stipulations, it can be seen that Vāstu had also envisaged a well-ventilated and energy efficient dwelling after considering all site conditions, environmental factors and climatic conditions.

CHAPTER 4

CONSTRUCTION MANAGEMENT AND CONSTRUCTION MATERIALS IN VĀSTU

4.1 INTRODUCTION

The organizational structure is an essentiality of any construction project. This includes questions like what are all to be done and who will do it? To assign specific jobs, what are the selection criteria and what all are the skill sets required? This is the simplest management system followed in any work site. Surprisingly this was properly conceived in Vāstu. Classification of Śilpins, their qualification and duties are clearly spelt out in the texts. Need for motivating Śilpins etc. are also mentioned.

4.2 CLASSIFICATION OF ŚILPINS

The Vāstu tradition had identified the two major bifurcations in any building project. One is design and the other is construction.

The conceptual Design and Engineering and overall supervision up to the completion of the project was the duty of Ācārya. Once a client decides to build anything whether it is a village, a town, a residence or a reservoir, a well or place of worship, initially an Ācārya must be selected and appointed as a prime consultant. This activity is called 'Ācāryavaraṇam'.

grāmādikaṃ vālanṛgṛhādikaṃ vāpyādikaṃ vā vibudhālayaṃ vā/
yaḥkartumicchatyathasaṃvedastaiḥvṛtoguruśīlpibhiretadartham//(SR 1:29)

Literal translation: *For constructing village, residence, pond, well, temple or anything initially it is required to choose an 'acharya' along with with 'Silpins'.*

Manuṣyāla Candrikā also says the same thing in other words. *'Those who are desirous of building a house must accept (appoint) an Ācārya'.*

martyo viprādivameṣviha bhavanavidhānotsukaiyaḥ sa pūrvam/
vipraṃ taddeśasambandhinām akhilaguṉairanvitam saṃvṛṉīta//(MC 1:9)
vedāgamādivihitānyavadhārya vipraiḥkāryovidhiḥ sakaladevanarā layānām|
tadvākyataḥsakaladhāmasu mṛcchilāderanyonyamelanamuśanti hi kārukṛtyam ||

Literal translation: *When any person belonging to the varnas starting from Vipra is desirous of building a house, he must first accept an Ācārya (learned preceptor), who is associated with the locality and who has all the (required) virtues. Then after selecting the plot suitable for the class of the person who seek his advice, he (the Ācārya) should perform the rites of worship (of Vāstu) and get the building constructed according to the prescriptions in the texts by skilled craftsmen. It is the Ācārya, who should give the prescriptions of the houses of gods as well as humans, after carefully considering what have been stated in the ancient texts like the Vedas and agamas. Constructing the buildings in accordance with his (Ācārya) prescription by joining the mud, stone etc.is considered as the job of the workmen.*

The texts recommend that the qualities of Ācārya whom the client (owner) appoints for drawing up plan for his building shall be verified. Specifications given are as per the social structure prevalent in olden days. However, the sum and substance of the qualities described is that he shall be highly knowledgeable with all desirable virtues and must be righteous. MC additionally specifies that Ācārya must be *‘taddeśasambandhinām akhilaguṇairanvitam’* meaning he should be coined with all good qualities and moreover conversant and familiar with the locality and related local attributes that a building design needs. Here the attributes are nothing but the geography, climate and other peculiarities of the locality which are influencing factors in design and construction. In a period when building codes relating to design loads, wind speed etc. (IS 875) and earthquake code (IS 1893) were not in existence, a designer who is aware of the locality was a must and his acquired knowledge from his predecessors regarding nature of soil, inundation levels, climatic conditions, durability and suitability of building materials etc. were relevant. This might be reason why during recent floods also, many traditional buildings stood unaffected while recent constructions affected heavily.

Ācārya who has knowledge of all rules and regulations set by ancient texts shall prepare the ‘Method statements’ *(*kāryavidhi*)* for all works and men at site need only accrue out construction work as per his direction. Thus, the role of design consultant is clearly spelt out in the ancient texts.

The next is the chief of the construction (master builder) or Perunthachan. One such Perunthachan is a legendary figure in Kerala history who is supposed to have lived in 4th century, as he is considered as son of Vararuci and brother of Mezhathur Agnihotri (b.343 CE). Many wonderful creations some of which still exists are said to have been the creations of legendary Perunthachan of Kerala. The name of the master builder of the famous Brihadeswara temple built during (1003 and 1010 CE) under the tutelage of Cholas king is found in one of the inscriptions as *‘Kunjaramallan Rama Perumthachan’*. This attests that due acknowledgments were given to master builders in ancient India.

The Construction in Charge or Engineer-in-charge of construction or master builder is called Sthapati. One who assists him in taking measurement and supervising works etc. is called Sūtragrāhī. It means one who holds the measuring rope (tape). In modern parlance, he is a Supervisor or an Overseer. The skilled workers are of two categories; the carpenters called Takṣaka and masons and joiners called Vardhakī. Thus, there are four classes of people at work site who will be led by the Sthapati. Sthapati in turn gets guidance from Ācārya regarding work. The texts have explicitly depicted the skill set required for the Sthapati or Engineer-in-Charge who leads the team of workers site and manages the work properly.

Sthapati is defined as *‘one who designated to build’ – “sthapati sthāpanārha”.* In modern construction practice, all work at the site is the sole responsibility of the Engineer-in-charge. Hence all the work-related permits are signed off by him. Hence work proceeds and progresses with his nod only. In traditional context, Sthapati is the Engineer-in-charge, hence the statement: ‘He shall be designated or made responsible’ is meaningful. The texts give the qualities and skill sets required for a Sthapati. He shall be:

1. Adept in all sciences
2. Physically fit

3. Righteous
4. Kind
5. Ego less
6. Devoid of Jealousy
7. Having good family lineage.
8. Expert in Mathematics
9. Knowledgeable in ancient texts
10. Always happy (composed)
11. Generous
12. Drawing skills
13. Knowing the details (engineering) of all localities.
14. Honesty and Integrity
15. Control over the passions
16. Healthy (Physical)
17. Healthy (Mental) or devoid of any psychological problems.
18. Free from seven evils (Hunting, gambling, womanizing, drinking, extravagancy, uncontrolled speech and uncontrolled deeds)
19. Having a good name (Reputation)
20. Good interpersonal dealings
21. Expertise and ripe knowledge in Engineering (Vastuvidya).

Śilpiratna and *Vāstuvidyā* have quoted the following verse as such and *Manuṣālaya Candrikā* has its own diction.

sarvaśāstravihitakriyāpaṭuḥ sarvadāvahitamānasaḥ śuciḥ/

dhārmikovigatamatsarādiko yaśca sa ca sthapatirastu satyavāk//MC 1:12

Literal translation: *The four classes of builders viz. Sthāpati, sutragrahi, taksaka and varadhaki, each one adept in his work, are to be selected systematically. Let the one, who is adept in the techniques prescribed in all texts, whose mind is always calm, who is pure and rightful, who is free from unfair competition and who speaks only truth, be Sthāpati, (chief of construction).*

4.3 HUMAN RESOURCE MANAGEMENT IN VĀSTU

According to *Manuṣyālaya Candrikā*, Sthapati shall be knowledgeable in all sciences, he shall be practical and should possess problem solving attitude with a cool and always composed mind (analytical mind) and must be clean and tidy. He shall be righteous and devoid of unnecessary ego and unfair competition. Moreover, he shall be truthful. MC (c.1550) has rightly emphasized on two relevant aspects which ancient texts have omitted or missed. The aspect of practical knowledge is very much needed quality as Sthapati has to lead a construction team. Similarly, a well-dressed, neat appearance in site is very much required as head of the team.

According to modern management theory, three types of skill sets are required for a Manager. They are technical, human and conceptual skills. Technical skills are required to accomplish the assigned task. Here job knowledge, experience in the field etc. matter. Human skills are required to deal with subordinates and superiors as well. *'Managers with good human skills understand their role inside the manager/employee relationship and how important things, like trust, cohesion, fairness, empathy, and* *good will, are to the overall success of the organization. Human skills help the manager to communicate, lead, and motivate an employee to work towards a higher level of productivity'. Interpersonal skills are also must*.

Conceptual skills are those skills a manager must possess for decision making, problem solving, for making creative suggestions etc.. The different qualities suggested in Vāstu texts for a Sthāpati can also be categorized under the above skill set and can observe that most desirable skills have been covered in it. The categorized list under modern management theory is given in the following table.

Table 4.1 Skill set

#	**Skill set**	**Category**
1	Knowledge in all Sciences.	**Technical skills**
2	Expert in Mathematics	
3	Knowledgeable in ancient texts.	
4	Drawing skills.	
5	Awareness of past relevant engineering data of all localities.	
6	Mastery in Engineering	
7	Practical experience and expertise.	
1	Righteous	**Human skills**
2	Compassionate	
3	Devoid of malice	
4	Free from unfair competition	
5	Good Family background.	
6	Generous	
7	Honesty and Integrity	
8	Control over passions.	
9	Physically and mentally fit	
18	Free from bad habits.	
19	Good interpersonal relations	
1	Reputation	**Creative skills**
2	Analytical Mind	
3	Problem solving ability	

Next comes the Sūtragrahī. His required skill sets have been specified in '*sūtragrāhyādilakṣaṇam'*. As mentioned earlier he supervises job and ensures accuracy of measurements and quality of work and its compliance with the design.

'sthapate tasya śiṣyo vā…… mānonmānapramāṇavid' meaning Sūtragrahī will be the disciple of Sthapati or his trained son (Neelakantanasari,1987). He takes instructions from Sthapati and is knowledgeable in all items of work. He will be adept in setting out, units and measurements of all kind. Here mentioning of *'mānonmānapramāṇam'* has a wide meaning indicating all types of measurements. This covers length, area volume, contour, vertical measurements and verticality measurements. The similarities in a modern construction site management between traditional concepts are obvious.

'Next comes 'Takṣaka' which verbally means *'one who breaks'* as defined in *Mayamata*.

takṣaṇāt sthūlasūkṣmānāṃ takṣakaḥ sa kīrtitaḥ/ MM 5:21

Here Takṣaka should be expert in making wooden members after sawing, cutting and planing. As per tradition Takṣaka is not only a carpenter but also a sculptor who can make wooden as well as clay models. Takṣaka must possess good qualities and he should be physically and mentally strong. He should have adequate skills to carry out all building works independently. He must be reporting to Sthapati and must always move along with Sthapati and takes instructions from him. It appears that the Takṣaka is a foreman heading all carpenters and masons. Vardhaki's duty is erection of assembly and joinery works. He takes instructions from Sūtragrāhī. In the current practice they are called 'mate' in construction sites, they control masons, joiners and skilled workers.

Need for motivating workers

The section of classification of Śilpins concludes in *Mayamata* (c.300 BCE) with a verse reminding all that '*without those four categories of skilled work men, no construction work can be accomplished and hence they deserve honorable treatment (pūja) always'* (Sastri, 1919). This is repeated in all later texts and MC has further elaborated it. The need for keeping good work environment and keeping workers content and satisfied, is categorically mentioned in MC. *Since no idea can be materialized without workmen, keeping them happy is all the more important and is the duty of the Ācārya.*

> vinā sthāpatyādi catuṣṭayena gṛhādikarturna ca śakyate'smāt/
> prasāditaistairatha vipravaryaḥ susūkṣmadhīḥ kārayatāṃ gṛhāṇi//(MC 1.14)

Literal translation: *Without these four classes of Śilpins, Sthāpati etc. it is not possible to construct a house. Hence intelligent Ācārya should get the house constructed by making all of them (workmen) happy and contented.*

This parallels with the modern management policy of *'contented and happier workmen and pleasant work environment increases productivity and quality'*.

There are three influential variables of productivity according to modern management practices and all these were met in those days as evident from the texts. The three aspects are supervisory behavior, incentive payments, and the task itself. Regarding the incentives, there was a system of paying handsome gifts to workers apart from wages depending upon the status of the owner. Ensuring these incentives was also the duty of the Ācārya.

kartā Catha kriyāntemahitaguruvaraṃ bhojayitvā yatheṣṭham/

gobhūmyādyaiśca datvā vidhivadanavahitodakṣiṇāṃ mukhyarūpām/

ājñāmādāya tasmānnikhilamapijanamprīṇayan bhūridānaiḥ/

svīyaiḥ svārthe svagehe suciram adhivaset pūrṇakāmaḥ sukhena// (MC 7.37)

Literal translation: *Then; at the end of the rites, after feeding the revered acarya and offering him cow, land etc. and the main daksina according to the prescriptions and taking his permission, the owner should please all persons with several gifts and live happily in the house, fully satisfied for a long time along with the family*.

Even now the tradition continues as workers connected with house building are given gifts and sumptuous feast before house warming.

Regarding wages, *Arthaśāstra* has mentioned that skilled labour like carpenter shall be paid 120 Paṇas (Chapter 5/3/16) when the ordinary worker's wages was 60 (5/3/17) Paṇas. *Arthaśāstra* ensures proper payment of wages by imposing fine on non-payment of wages (Namboothiri, 2015).

Arthaśāstra, chapter 3 /13/33 says: "*In the case of non-payment of wage, the fine is one-tenth or six paṇas." Arthaśāstra*, chapter: 3/13/34: "*In the case of denial, the fine is twelve paṇas or one-fifth*." *Arthaśāstra* has also dealt with the need for labour welfare in detail (Jaya, 2011).

Kauṭalya's *Arthaśāstra* was popular in Kerala which is evident from the fact that there is a translation of the same in Malayalam prose (*Bhāṣākauṭalīyam* -probably the first prose in Malayalam literature) dating back to 12th Cent.

4.4 SOCIAL ASPECTS OF POPULARIZING VĀSTU TEXTS

Finally, regarding task, the unique aspect was that all workers were trained not only practically but theoretically also. In a period when Sanskrit learning was restricted to so-called upper-class, the working class was given opportunity to learn Sanskrit to access Vāstu texts, which had much impact in later period from a social point of view, triggering demand for social justice and equality for the lower tier of community. Theoretical training of workmen helped them to appreciate their task more as well as to deliver good quality of work. The renaissance that happened in Kerala due to the influence of 'Bhakti movement' had shaken the base of hierarchy based on caste, but slowly the men of letters from any community gained respect from early 16th Cent. Ezhuthachan's *Rāmāyaṇam* in Malayalam is a landmark in this. This also triggered a literary movement accessible to all, irrespective of the social tier and Vāstu texts have played an important role in this.

4.5 MATERIALS OF CONSTRUCTION

4.5.1 Introduction

In a period where transportation of building materials was very difficult, local materials were used and insisted. Abundance of timber in Kerala made Kerala constructions timber intensive when compared to the adjacent state Tamilnadu where natural stones were lavishly used. Instead of rock, use of laterite was very common in Kerala. Use of burnt as well as un-burnt bricks (adobe) was also not uncommon. Similarly, for roofing, apart from thatching with palm/coconut cadjans, tiles were prevalent. Copper plate roofing for temples and other religious structures was also prevalent. Lime was used for bonding material for masonry and plastering. Treatment of lime by adding organic/inorganic admixtures was practiced. Mud for brick/tile making was also modified by adding admixtures of various types. Classification of timber based on its properties and treatment of timber were also done. Different categories of timber were recommended for different uses. Engineered soil/clay (cob) was used for wall construction. Uses of iron /copper/ alloy nails have been recommended.

śilaṭakāsudhādāruṃṛtsnāmṛloṣṭalohakāḥ/

ete vimānakaraṇe divyatvena nirūpitāḥ// (SR 1.14)

Literal Translation: *Stone, Bricks, Lime, timber, tiles, cob and metals are considered best for the construction especially for the abode of Gods*.

The above verse has summarized all the specified materials.

4.5.2 Stone

The rock in modern geology has classified as igneous rocks, sedimentary rocks and metamorphic rocks. Such a classification is not seen based on the origin of rocks. Only qualitative classification based on colour, nature of grains, texture etc. are seen. Another classification in Vāstu texts are rocks in to Masculine, Feminine and Neutral.

gurvīdhīraravāsphuliṅgabahulanyagrodhabodhicchada-

prakhyābimba(vidhau) viśālabahulā grāhyā śilāpauruṣī/

rambhāpatranibhānacātibahulāsnigdhasvanāśītalā

straiṇīpīthavidhaudvilakṣmabhidurāklaibīpadābjārpaṇe// SR 14:15

caturaśrācadīrghaśrāstrīśilāpīṭhikocitā

tryaśrātadāyatāṣaṇḍājñeyāpādaśilocitā// SR 14:171

Literal translation: *This classification is basically based on the hardness of the rock. There was practical wisdom to select the type of rock for each type of work such as columns, fine sculpture work etc.*

'*It is said that stones which emit a long, deep sound like that of a bell are known as male stones, the stones which have a long vibration like that of a brass vessel are called female stones and the stones that are crude and uneven, with little resonance, are called neutral stones. These types of stones are used to make musical pillars. The sculptors select the rock (stone) to make these pillars by tapping them' (Prasad and Rajavel, 2013).* Thus, it can be seen that practically the classification was working.

Another interesting mention in the Vāstu texts is about the presence of fossils in rock. These fossils are said to be toxic and texts strictly advice to avoid it. Some tests have also been specified to check the presence of fossils. (SR Verses 21 to 43). Similarly, the mention about the age of rocks and direction of lying of rocks are also worth noting as it is scientifically known that rocks are formed in the geological past in different periods and by flow of lava from volcanic eruption.

4.5.3 Bricks

For making bricks and tiles, among the four types of clay (Chikkana, Pandara, Salona and Tāmraphulla), the Tāmraphulla is recommended for brick making. The meaning of Tāmraphulla indicates that it has a reddish tint (copper shade) which obviously clay settable for brick ought to possess due to its iron content. *Mayamata* classifies clay into four types, ūṣaram (marine clay), pāṇḍuram (kaolin), kṛṣṇa chikkanam (black clay) and Tāmraphulla (reddish clay). The qualities of clay for brick given in *Mayamata*, SR etc. are same.

tuṣāṅgārāsthipāṣāṇaśarkarākāṣṭhaloṣṭakaiḥ/

varjiūāsūkṣmasiktātāmraphulleṣṭakocitā// SR 14:47

Literal Translation: *The clay for making bricks shall be free from impurities like husk, charcoal, bones, stone pieces, boulders and must contain sandy particles of fine size. This type of Tāmraphulla is suitable for clay tiles and bricks.*

Through mixing of clay is recommended before brick moulding. An admixture made from decoction made from Nalpamara trees (Four trees of ficus family) and Nenmenivaka mixed with another decoction using triphala (Nellikka, Thannikka and Kadukkaa). In recent years, bricks are made of pure suitable clay. No admixtures were used. In recent years many admixtures are there in the market as additives of cement and concrete. In Vastuvidya, it can be seen that the clay for brick manufacturing was also treated with herbal admixtures to get more durability and strength. There is a scope for further research in this topic of herbal admixtures based on their specifications in Vāstu texts. The maximum size of bricks made in those days was $36cm \times 18cm \times 12cm$. soaking in water for one to four months is also recommended in *Mayamata*.

Five types of lime-cements are specified. Each type is made with different admixtures of lime and fine sand in different proportions. Each type of Lime-Cement was powdered and kept for use. When we examine the ingredients, surprisingly, it is a mixture of argillaceous and calcareous materials with some admixtures having cementing properties. Only difference is that no heating is done and the reaction is taking place at normal temperature. On detailed study and chemical analysis, there is a scope for developing a new ‘Green Cement’ based on the specifications from the above.

karālamudgayoḥ pūrvoktamānenasikatānvitam |
caṇakasya ca cūrṇasya ca yatpiṣṭaṃ kalkamiṣyate || SR 16:64

Literal translation: *When sand is required quantity is added to ‘kahala’ and ‘mugdhi’ along with ‘chana; is called ‘kalka’.*

Ongoing through the above description, the final product *‘kalkam’* resembles ‘clinker’ of modern cement manufacturing process. Finally, in lime-cement mortar also, herbal admixtures – *Chikkana* and *Badhodaya*- are suggested to be added. Details of admixture preparation are also given in detail.

cikkaṇaṃkevalṃkvāthaṃ baddhodakamitidvidhā |
niśchidramiṣṭamānenakṣetretviṣṭakayācite || SR 16:65

Literal translation: *Two types of admixtures in the name chikkana and baddodaka are commonly used.*

4.5.4 Timber

Classification of timber according to Vāstu: As mentioned elsewhere Vāstu classifies timber into Antassāra, Bahissāra, Sarvasāra and Nissāra. of these the Nissāra category is soft wood and not useful for any construction. Excluding the soft wood, IS 883 (1994) also classifies timber into three groups (A, B &C) based on their structural properties, refer clause 6.2.

asāraśākhinaḥ sarvān varjayed gṛhakarmaṇi

ṛjavaḥ sāravantaścadṛḍhāścacirajīvinaḥ ||

varṣavātātapasahā jalasthalabhavāśca ye

tattaddeśocitāḥ śastā grāhyāḥ syuḥ śubhadhāmasu || SR 16:88

Literal translation: *Timber without bends, with hard wood, with adequate strength and durability, with inherent strength to resist sun and rain, standing without any problem in outdoor and that too in water over and above can be considered for construction purposes.*

śākāsanamadhūkaṃ ca sālaṃ sarja sacandanaṃ |

panasaṃdevadāruṃ ca śaṃsanti gṛhakarmaṇi || SR 16:91

Literal translation: *For all construction works, Teak (Tectonagrandis) Venga (Petrocarpusmarsupium), Ilippa (Madhucalongifolialatofolia), Sal (Shorearobusta), Marutu (Terminaliapaniculata) Sandal (Santalum album), Jackwood (Artocarpusheterophyllus) and Vella-devadaram (Erythroxylummonogynum)and Himalyan Devadaru (Cedrusdeodara) are considered to be very good.*

In modern construction also, these varieties are used except Sandal wood because of its prohibitive cost. But it is very good for handicraft work. The salient engineering properties of these timbers are available in IS 883-1994 and A Hand book of Kerala Timbers.

For timber column construction, following varieties of wood are specially mentioned in Silparatna.

khadirasālo madhukaḥ sabakastathaiva śiṃśipaścaiva |
tathārjunākaṇaukiriṇī ca padmacandanau vṛkṣau ||
viśikhodhanvanaḥpiṇḍī siṃho rājādanaḥ śamī |
talakaṃ ca drumāścaite stambhe vṛkṣāḥ samīritāḥ || SR 16:95

Literal translation: *Khadira (Karngali), Sal, Iruppa, Savanam (Erukku), Irul, Nirmaruthu,Venga, Kumiz, Pathimugham, Sandal, Vishikam (ambottal), Dhanwanam, Asokam, Ilanji, Konna, Vahni, Pachotti.), are recommended for columns.*

On verification, it is found that these varieties have more compressible strength also along with flexural strength. Other acceptable timbers listed in the same texts are Aryaveppu, Vaka, Attuvanji, Kacholam, Thotukara, Anjili, Ezhilampala and Ayamodakam. All timbers except Anjili in this list comes under group C as per IS classification (IS 803).

praveśya śastadvāreṇa śilpaśālāsthaletataḥ |
vālukśsañcayedāruṃ śāyayet pūrvamastakam || SR 16:116
na parā vartanaṃ kuryādaṣṭapañcatrimāsataḥ |
paścādiṣṭapramāṇenabhittvākrakacakoṭinā || SR 16:117
antarmukhaṃ bahipṛṣṭhaṃ prakalyātrāñkamunnayet |
mūlecāgretathākṛtvātrāntaramunnayet || SR 16:118

Literal Translation: *The timber shall be kept over heaps of sand inside a temporary shed after in the East-West direction taking inside the plot through the main gate. For seasoning it shall be kept for 8, 5 or 3 months. Then scantling shall be made after sawing. The marking shall be made to identify the top and bottom of the timber.*

Importance of seasoning was identified by our ancestors. Usually logs were in a work shed with its head towards East on sand heaps for three to eight months. After sawing, the head and bottom portions were marked. Tradition insists to keep the bottom of timber as bottom of the structural members such as columns. This makes sense as bottom has more stress carrying capacity from structural point of view. If marking is not there, by a floatation test using a small cut piece the bottom could be determined. As per IS 1141(1993), Clause 8.2.4 states that '*Air seasoning is usually a slow process. The actual period required will vary with the size and species of timber and the seasonal variations of climate. Ordinarily, timber should not be considered as fully air seasoned in less than six months. Planks of broad-leaved species (hardwoods) 25 mm in thickness may take three to four months to season in a moderate climate. Scantling as used for door and window frames may take from 6 months to a year to attain reasonable degree of seasoning'*. The treatment for wood for flag posts in Kerala to get durability and serviceability for minimum 6 to 8 months in exposed condition is scientific. The process of leaving the wood in oil medicated with turmeric, camphor etc. is an organic anti-termite treatment as well as a seasoning technique.

4.5.5 Roofing tiles

It is a general belief that roofing tiles was introduced by Europeans in South India. The *Vāstuvidyā* (14^{th} Cent.) which is a popular text in Kerala gives details of different types of roofing tiles with its name, shape and procedure for making it.

nīpraloṣṭaṃ tūrdhvaloṣṭaṃturyuśraṃ kūraloṣṭakam |

dravyaśraloṣṭaṃ kīlaloṣṭaṃ kṛśasthūlāgraloṣṭake || SR 16:122

gatakarṇaṃ koṇaloṣṭaṃ puṭaloṣṭaṃtathaiva ca |

loṣṭānyekādaśaiteṣāmāyāmādikaucyate || SR 16:123

Literal Translation: *Nipraloṣṭa, Ūrdhwaloṣṭa, Turyaloṣṭa, Kūrloṣṭa, Vyaśraloṣṭa, Kīlaloṣṭa, Kṛśāgraloṣṭa, Sūlāgraloṣṭa, Garttaloṣṭa, Koṇaloṣṭa and Puṭaloṣṭa.Thus there are 11 types of tiles. The rules for its dimension are said below.*

The eleven types of tile are Nipraloṣṭa (Eve tile), Ūrdhwaloṣṭa (common tile), turyaloṣṭa (square tile), kūrloṣṭa (Hip tile), vyaśraloṣṭa (diamond tile), kīlaloṣṭa (Pin Tile), kṛśāgraloṣṭa (Spade tile), śūlāgraloṣṭa (showel tile), garttaloṣṭa (valley tile), koṇaloṣṭa (corner tile) and puṭaloṣṭa (Edge tile). With the introduction of MP tiles, the special tile production ceased in Kerala. SR also quotes all the verses from *Vāstuvidyā*.

Roof covering with copper plates and gold-plated sheets are also given in several texts including *Mayamata* and MC. Quote from SR is given below.

kīlaśūlādinirmāṇe lohaḥ kṛṣṇaḥ praśasyate |

suvarṇaṃ rajataṃtāmraṃ pūjitaṃ loṣṭakarmarṇi || SR 16:151

kāṃsyapittalakādīni madhyamānīritāni hi |

stūpyācchādānake sarvamiṣṭam kṛṣnavivarjitam || SR 16:151

vallimukulapuṣpādikaraṇenikhilāḥ śubhāḥ |

bimbapīṭhādikaraṇe śastaṃ vakṣyāmi tadvidhau || SR 16:152

Literal Translation: *Now the names of materials made of metals are given. The nails and spade are made of iron. With gold, silver and copper roof covering plates are made* *ideally. Bronze and brass can also be used for this purpose. Stubha can be made of any metal other than iron. For decorative works in the shape of creepers, buds, flowers etc. can be made of any metal. For idols and its base, the rules will be separately dealt.*

Metallurgy was a much-developed portfolio in ancient India. '*The earliest forged iron in the world is the famous iron pillar in Delhi dated by the inscription to the Gupta period (ca 400 CE). It is about 7-meter-high and its weight is about 6 tonnes. Apart from the dimensions, another remarkable aspect of this pillar is the absence of corrosion*' (Balasubramanian, 2000). Five metals (*Pañcalohas*- Gold, Silver, Copper, Iron and Zinc) and many alloys were known from Vedic period. The following quote on zinc is self-explanatory to prove India's supremacy in the subject. Referring to history of Zinc, in 1597, Libavius, a metallurgist in England received some quantity of Zinc metal and named it as Indian/Malabar lead. In 1738, William Champion who is now is credited with first patenting was rejected by the patent court on grounds of plagiarizing the technology common in India (Bose et al., 1971).

4.6 CONCLUSION

Summarizing the content of the chapter, Vāstu had envisaged all aspect in project/ construction management system for design and construction and quality control of the buildings including budget control.

kuryād dravyavaśādihaikamuditān vṛkāṃśca dikṣukramāt | (MC 7:35)

Literal translation: *Hence choice shall be made according to availability of funds.*

Also, Vāstu has a clear idea about the classification and quality of construction materials. Various herbal admixtures specified in the texts require special attention as it opens up certain possibility of developing some ‘green products’. Moreover, as Vāstu advocates lime mortar and formulations with lime must be put to use wherever possible as carbon footprint of lime is low as it absorbs carbon during setting (Schilegel et al., 2014).

CHAPTER 5

SUPER STRUCTURE AND STRUCTURAL ENGINEERING IN VĀSTU

5.1 INTRODUCTION

On examining the rule for fixing the lateral dimensional of a column (pillar), and other structural elements in Vāstu texts, a structural engineer will definitely agree that in approach and philosophy, ancient Indians had maintained the same scientific and rational thanking as modern engineers have and it will not be improper to say that they had anticipated Euler's theory (Timoshenko et.al, 1963) in column design.

5.2 COLUMN DESIGN

The pillars (Columns) of important structures were mainly made of carefully selected solid rock architecturally treated from bottom to top. Timber (wooden) columns and masonry pillars are also not so uncommon.

The shapes generally adopted are Square, Octagon, Hexa-decagon (sixteen-sided polygon) and circular. Regular polygons (Square, Hexagon etc.) and circular are the common geometry adopted for columns and in special occasions rectangular and T Shaped columns are seen to have provided. As these pillars were mainly rock cut or timber for architectural beauty, above cited different shapes were mixed in a column producing many aesthetically pleasing combinations. These are also defined and named.

When homogeneous material is used, the determination of required size of a column according the material of construction and quantum of super imposed load is the main design step. The traditional rules are depicted below.

According to *Manuṣyālaya Candrikā* (MC):

> stambhoccābdhīṣu ṣaḍbhūdharavasunavadigrudrabhāgaikataḥ syāt
> stambhābdho vistṛtistadavasunavadaśarudrāṃśahīnogratāraḥ
> daṇḍāpyaścāyam etena ca kuhācidatho mīyate dārukkṛptau
> kuḍaīstambhāgratāroƒpyatha tadavayavākalpane daṇḍasaṃjñaḥ || MC 5.24

Literal translation: *The least lateral dimension shall be 1/4, 1/5, 1/6, 1/7, 1/8, 1/9, 1/10 or 1/11 of its height The effective height of the Pillar or column is defined as the measurement from the bottom of the Oma to top of Potikā or in other words it is the height including Potikā (Column capital) and Oma (Column Base block). However, the height of the Pedestal below the Oma will not be considered.*

According to Śilparatna (SR):

> stambhamūlaviśālaṃsyādevaṃsakalabhumiṣu|
> tasmādagraviśālaṃtukārayetpūrvamuktavat || SR 21.46

Literal translation: *Otherwise by dividing the height of column by six, seven, eight, nine, ten eleven or twelve the width of the column (at bottom) can be determined.*

The lateral dimension of the column shall be L/6 to L/12 where L is the height of the column as defined above. It is pertinent to note that the ratio L/D is identified as the key factor in the sizing of columns in the traditional texts. Moreover, in the all the texts they have stated the upper limit of L/D ratio as 11 or 12.

A chapter in *Matsyapurāṇa* (MP) (500BCE) deals with the design of pillars. It says:

> sūta uvāca - athātaḥsaṃpraṃvakṣyāmistambhamānavinirṅayam |
> kṛtvāsvabhuvanocchrāyaṃ sadā saptaguṇāṃbudhaiḥ, 1.
> aṃśītyaṃśaḥpṛthutvaṃsyādagreṇāvaguṇaiḥsaha || MP 253.1-2

Literal Translation: *Now shall dictate the rule for column sizing. Multiply the height of the column by seven (7) and then divide it by 80*.

Thus, the lateral dimension of the (square) pillar (d) shall be $\frac{7L}{80}$ where *l* is the height of the pillar. This works out to an L/D ratio of 11.42.

The *Bṛhatsaṃhitā* (BS) written by Varāhamihira (505–587 CE) specifies that the minimum lateral dimension of column at bottom shall be $\frac{9}{80}$ of height, (Puliyoor, 1998).

> ucchrāyahastasaṃkhyāparimāṇānyaṅgulānibāhulyam |
> śāśadvaye$f$pikāryasārgha tat syādudumbarayoḥ || BS 51.27

Lateral Translation: *An eightieth part of nine times the height gives the width of a pillar at the bottom; and the same lessened by a tenth is its width at the top.*

In the *Bṛhatsaṁhitā* of Varāhamihira, the L/D ratio recommended is 9/80. The tapering adopted is 1/10 when lateral dimension of column at bottom is considered, the bottom and top width will be as follows.

Bottom width = $\frac{9L}{80}$;

$$\text{Top width} = \frac{9L}{80} - \left(\frac{9}{80}\right)\frac{L}{10} = \frac{81L}{800}$$

Usually in traditional construction, columns are slightly tapered and the tapering shall also be done in the same L/D ratio.

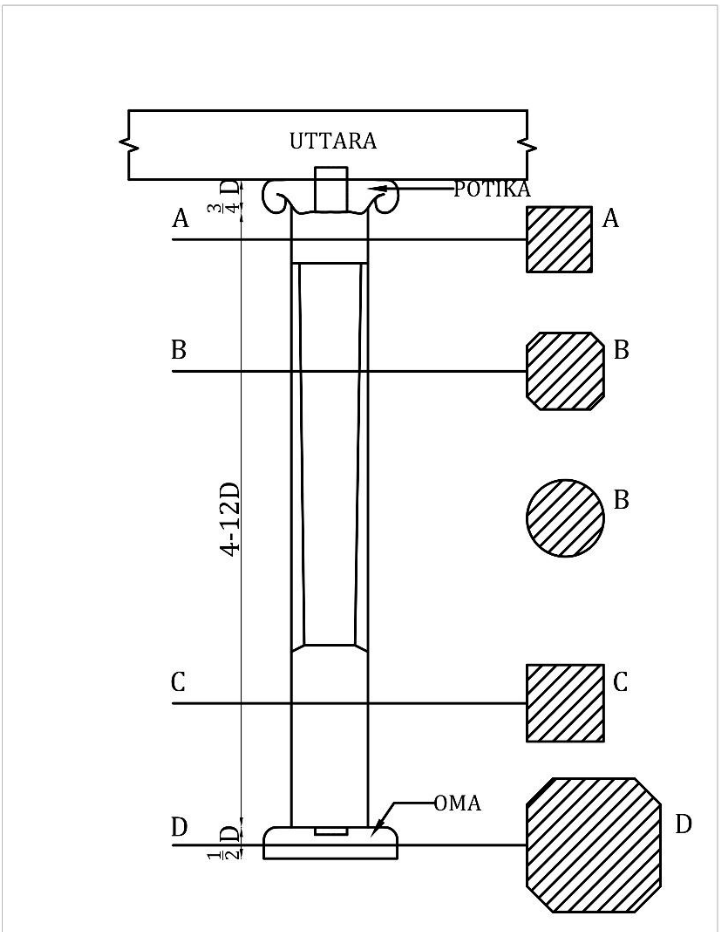


Fig. 5.1 Parts of Tapered column

In very ancient texts also only specific ratios are mentioned instead of range as in latter texts. The style of specific ratios is similar with Grecio-Roman order of column design.

In traditional buildings, the spacing between the columns never exceeded the column height and the span of the building never exceeded twice the height of the column. Thus, all these dimensions were related.

Thus, if we consider the total load transferred will be as follows: Let l is the effective height of column. As stated above the span in traditional buildings never exceeded twice the height and spacing never exceeded the height of columns.

Let w is the total load per unit area; Spacing between the columns = L; Span of the building = $2.L$

Let total Load = P

$$P = wL^2 \quad \text{.......................................} \quad (1)$$

Thus, Direct Stress

$$\sigma_c = P / A = \frac{wL^2}{D^2} = w\left(\frac{L}{D}\right)^2 = w\lambda^2 \quad \text{.......................................} \quad (2)$$

Where D is the lateral dimension of square column.

Assuming that column has approached the limit of Intermediate column:

Euler's Stress,

$$\sigma_e = \frac{P}{A} = \frac{\pi^2 E}{\left(L/r\right)^2} = \frac{k}{\lambda^2} \quad \text{.......................................} \quad (3)$$

Where

$$k = \pi^2 E; \lambda = \frac{L}{D} \quad \ldots\ldots \quad (4)$$

Applying Rankine-Gordon equation

$$\frac{1}{\sigma_{\max}} = \frac{1}{\sigma_e} + \frac{1}{\sigma_c} \quad \ldots\ldots \quad (5)$$

$$\frac{1}{\sigma_{\max}} = \frac{\lambda^2}{k} + \frac{1}{w\lambda^2} = \frac{w\lambda^4 + k}{kw\lambda^2} \quad \ldots\ldots \quad (6)$$

$$\sigma_{\max} = \frac{kw\lambda^2}{k + w\lambda^4} \quad \ldots\ldots \quad (7)$$

Maximum load that can be applied

$$w = \frac{\sigma_{\max} . k}{k\lambda^2 - \lambda^4} = \sigma . \left(\frac{1}{\lambda^2 \left(1 - \frac{\lambda^2}{k} \right)} \right) \quad \ldots\ldots \quad (8)$$

$$\frac{\sigma}{w} = \lambda^2 \left(1 - \frac{\lambda^2}{k} \right) \quad \ldots\ldots \quad (9)$$

Where

$$k = \pi^2 E; \lambda = \frac{L}{D} \quad \ldots\ldots \quad (10)$$

Here it may be noted that w is the load per unit area acting on the roof/floor and σ is the allowable stress and hence irrespective of the variation of the height, it will solely depend upon the selected L/D ratio only. Thus, any test carried out on scaled model will validate the structure with the same material and same unit load per area.

In modern practice also, in the structural design of any column the criteria are end condition (whether fixed/partially fixed/pinned etc.), Eccentricity & slenderness ratio. The codes have set limits for eccentricity and slenderness.

In this context, it may be noted that in the modern design practice we are considering minimum eccentricity as per IS 456: 2000;

$$\frac{L}{500} + \frac{D}{30} \leq 20mm \quad \text{.......} \quad (10)$$

Where *l* is effective height of column measured in *mm* and D lateral dimension under consideration in *mm*. The maximum height of column specified as 8H or 5760*mm*. Then using *l*/D as 12 (Max). The lateral dimension will be 5760/12=480. In such a case the eccentricity as per the above clause will be

$$e = \left(\frac{5760}{500} + \frac{480}{30} \right) = 27.52 \quad \text{.......} \quad (11)$$

Applying a factor 0.75 for effective height after considering the deductions for Oma and Potikā; e=20.25 which fairly matches with modern stimulation regarding eccentricity limit. Thus, it may be noted that the maximum column height specified in the traditional texts has also relevance when viewed from modern theory.

In the façade of most of the Kerala temples, a tall open structure can be seen which is called Ānakkoṭṭil which essentially required tall monolithic pillars in the range of 5.76 metres height. This might be the longest Column one can identify in the category of traditional buildings in this region.

For columns using homogeneous material, the current practice is to determine the required size of a column according to the material of construction and the value of expected super imposed load (Pillai, 2005). On examining the traditional method of determining the size of column, it could be seen that, similar to the modern practice, the key role of the parameter, slenderness ratio have been identified. The slenderness ratio is the ratio of the lateral dimension (D) to the height (H) of a pillar or a column.

During medieval period, in the South India, there was a surge in the development of Vāstuvidyā and many outstanding books were written in this portfolio. Of these *Manuṣyālaya Candrikā* depicts as follows:

> stambhoccābdhīṣuṣaḍbhūdharavasunavadigrudrabhāgaikataḥsyāt
> stambhābdhovistṛtistadavasunavadaśarudrāṃśahīnogratāraḥ |
> daṇḍāpyaścāyametenacakuhācidathomīyatedārukkṛptau
> kuḍaīstambhāgratāroƒpyathatadavayavākalpane daṇḍasaṃñaḥ || MC 5:24

Literal translation: *The bottom width of the column will be* $\frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \frac{1}{7}, \frac{1}{8}, \frac{1}{9}, \frac{1}{10}$ *or* $\frac{1}{11}$ *of the height of the column and the top width will be reduced by* $\frac{1}{8}, \frac{1}{9}, \frac{1}{10}$ *or* $\frac{1}{11}$ *of the bottom width. The top width is called daṇḍa. Then by this, dimension of timber works* *is computed. The top width of the wall embedded pillars (pilasters) is taken as Daṇḍa (modular unit) for its decorative works.*

Thus, lateral dimension shall be $\frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \frac{1}{7}, \frac{1}{8}, \frac{1}{9}, \frac{1}{10}$ *or* $\frac{1}{11}$ of its height. When columns are tapered, the ratio shall be $\frac{1}{8}, \frac{1}{9}, \frac{1}{10}$ *or* $\frac{1}{11}$ of bottom width.

In the above description, three aspects of structural engineering are covered (Refer Fig. 5.2):

1. There is a lower limit for L/D ratio that differentiates column and pedestal.
2. There is an upper limit for L/D ratio that differentiates a short column and long column.
3. In the case of tapered columns, the tapering ratio is also important to ensure even stress distribution.

The verses cited above apply to both timber and rock cut (granite) columns or pillars. Hence initially comparison of this with the provisions in Indian Standard: Design of Structural Timber in Buildings- Code of Practice: IS 883:1994 is made.

Referring to clause 7.6.1, Solid Columns are classified into short, intermediate and long columns depending upon their slenderness ratio (L/D) and specified that for Short columns, L/D must not exceed 11. The current code provision exactly matches with the rule in *Manuṣyālaya Candrikā* (MC).

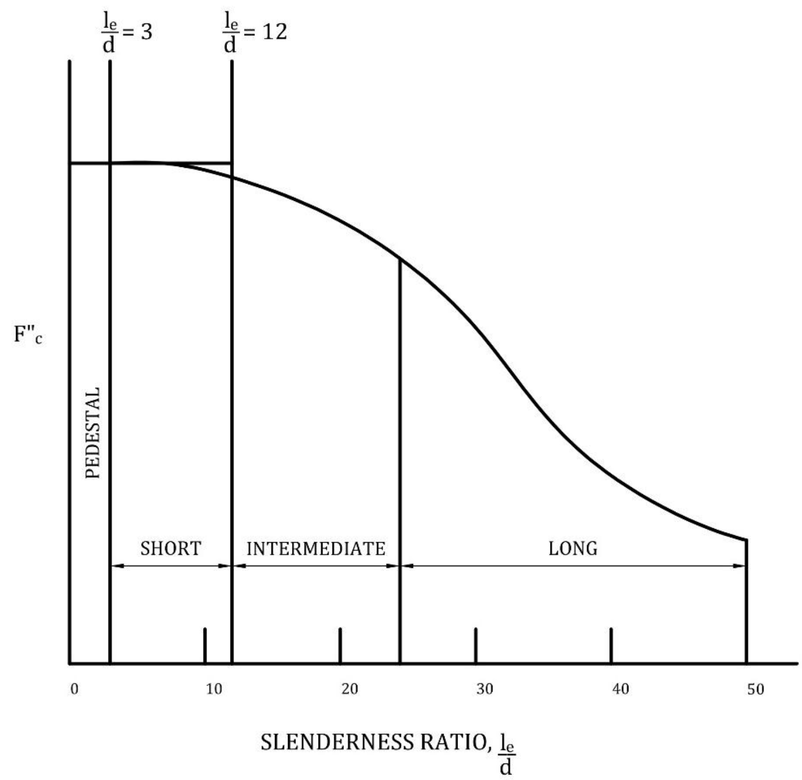


Fig. 5.2 Graph showing slenderness limits

Clause 7.6.1.7 in the IS 883:1994 speaks about the rule for determining L/D ratio of a tapered column: '*The least dimension shall be taken as the sum of the corresponding least dimensions at the small end of the column and one-third of the difference between this least dimension at the small end and the corresponding least dimension at the large end, but in no case, shall the least dimension for the column be taken as more than one and a half times the least dimension at the small end'.*

The above detail can be worked out as follows:

Let the $\lambda = \dfrac{L}{D}$ and k be the ratio of tapering. Let D be the bottom dimension of column and D_t be the top dimension of column.

Then $D=\frac{L}{\lambda}$

$$\therefore D_t=\frac{L}{\lambda}-\left(\frac{L}{\lambda}\right)\frac{1}{k}=\frac{L}{\lambda}\left(\frac{k-1}{k}\right) \qquad \text{.. (1)}$$

Then as per clause 7.6.1.7 in the IS 883:1994 mentioned above, effective dimension to be considered

$$=D_e=D_t+\frac{(D-D_t)}{3}=\frac{D}{3}+\frac{2D_t}{3}=\frac{L}{3\lambda}\left(1+\frac{2k-2}{k}\right) \qquad \text{.................................. (2)}$$

Equation [2] Effective Lateral Dimension, $D_e=\frac{L}{3\lambda}\left(\frac{3k-2}{k}\right)=D\left(\frac{3k-2}{3k}\right)$

Then $\frac{L}{D}=\left(\frac{L}{D_e}\right).\frac{3k}{3k-2}$ .... (3)

As per *Manuṣyālaya Candrikā*, the above factor $\frac{3k}{3k-2}=\frac{24}{22},\frac{27}{25},\frac{30}{28} or \frac{33}{31}$

When we consider the highest value, i.e. $\frac{24}{22}$, in order to limit $\frac{L}{D_e}=12$, we have to adopt $\frac{L}{D}=\frac{12}{24}\times 22=11$. This may be one reason why MC specifies 11 instead of 12 as specified in other texts. Incidentally the value in *Matsyapurāṇa* also might have derived in similar lines from L/D=12 by using 33/31 factor. The same clause also states that this should not exceed one and half times the top dimension i.e. $\frac{3}{2}D_t=\frac{3L}{2\lambda}\left(\frac{k-1}{k}\right)$

Equation [2] Limit of lateral dimension $\frac{3}{2}D_t = \frac{3L}{2\lambda}\left(\frac{k-1}{k}\right)$

Code specifies that $D_e \leq \frac{3}{2}D_t$

Hence in order to evaluate the limiting value of k, let us equate [1] and [2]

$$\frac{L}{3\lambda}\left(\frac{3k+2}{k}\right) = \frac{3L}{2\lambda}\left(\frac{k-1}{k}\right) \quad \text{..} (3)$$

Solving $\left(\frac{3k+2}{3}\right) = \frac{3k-3}{2}$

$$\begin{aligned} &6k+4 = 9k-9 \\ &k = \frac{13}{3} = 4.3 \end{aligned} \quad \text{..} (4)$$

In the rule stated for tapering in MC, maximum is $\frac{1}{8}$ which is evidently less than $\frac{3}{13}$ satisfying the condition stipulated under the clause 7.6.1.7:IS 883:1994. Thus, the structural requirements, when tapering is adopted in columns, are also taken into consideration while prescribing the rules in traditional texts and are matching with modern code provisions.

Now regarding the third aspect, the lower limit, the specification in *Manuṣyālaya Candrikā* is remarkable. As per the clause 25.1.1 of IS 456-2000 a column or a strut is a compression member, the effective length of which exceeds (3) three times the least lateral dimension and hence when L/D is less than 3, it will be under the category of Pedestals and not columns. *Manuṣyālaya Candrikā* by specifying lower limit as 4 and upper limit as 12 indicates that the author, Tirumaṅgalattu Nīlakaṇṭhan, has fully conceptualised the structural behaviour of column, thinking much ahead of his time. Thus, setting a boundary between pedestal and column similar to that in modern Engineering theory is remarkable and pertinent as it signifies the proper understanding of the subject. Thus the range of short column is fully reflected in the verse*5:24,*'*Stambhoccā'* of *Manuṣyālaya Candrikā.*

The dictions in other texts popular in Kerala are also examined here. The popular text named *Vāstuvidyā* (VV) of anonymous authorship was written definitely prior to MC as MC refers to this text. This text probably belongs to 14th Century written earlier than *Tantrasamuccaya* (TS) written around 1450CE as internal evidences in the text indicate. The statement design of Column is depicted in Chapter 8 of VV which says:

> athapādasyadaighryeṇatadviṣkambhaṃcakārayet |
> darśanādrivasudvśrapāṅktirudrāṃśakaiḥkṛtam || (VV 8.16)

Literal Translation: *The lateral dimension shall be decided based on the length of pillar, as proportions of 1/6,1/7,1/8.1/9,1/10 or 1/11.*

The *Śilparatna* (SR), written in the year 1635CE by Śrīkumāra (c.1600-1675 CE), states that:

> athavācaraṇāyāmeṣaṭsaptāṣṭanavāṃśite |
> paṅktirudrārkabhāgairvābhaktebhāgāṅghrivistaraḥ || (SR 21.45)

Literal Translation: *The lateral dimension of the column shall be decided by dividing height by 6, 7,8,9,10,11 or 12.*

Thus, SR specifies that L/D ratio shall be 6 to 12 where L is the height of the column and D is the lateral dimension. Here it may be noted that SR includes 1/12 also.

Mayamata (MM) gives the bhaktimāna(spacing) and stambhamāna(column size). The spacing is depcted in the verse 25:13. The spacing of columns to be fixed from 1.5 H to 5 H with an increment of 6A.

> svārdhadvihastamārabhyaṣaṭṣaḍaṅgulavardhanāt/
> aṣṭahastāntamaṃghryuccātrayoviṃśatpramāṇakam//MM 25:18

Lateral Translation: *The height of the column is from 2 ½ H to 8 H at an increment of 6 A making 23 sets. Increment of height in 3 A is also allowable.*

> nandapaṃktyaṅgulaṃyāvatsaṃkhyayāpurvavattatiḥ
> pādoccairapirudrāṃśadharmanandāṣṭabhājite
> mūlatāraṃtubhāgenatattatbhāgonamagrataḥ | MM 25:20

Literal translation: *The size of column shall be 1/11, 1/10,1/9, 1/8 of height at base. The size at top shall 11/10 or 10/9 of the bottom dimension*.

Mayamata stipulates the upper limit of range as 1/11 similar to MC and tapering limits have also been specified. Thus, it is relevant to note that the ratio L/D is identified as the key factor in the sizing of columns in all traditional texts. Moreover, in the all the texts they have stated the upper limit of L/D ratio as 12 or 11 identical to the modern Engineering practice.

Referring to the Fig.5.2, based on Euler's analysis L/D ratio is very crucial in the classification of column as short, intermediate and long. In this context, it may be noted that for rectangular sections the slenderness ratio is proportional to L/D ratio. The above citations from traditional texts reveal that the authors have clearly understood the structural behaviour of the columns under the application of loads, as they have set lower limit as well as the upper limit for the short column scientifically. As stated above, the rule in the MC stating both the lower limit as 4 and upper limit as 11 is laudable.

As mentioned earlier, chapter two of *Nāṭyaśāstra* (300 BCE) deals with construction of theatre (Nāṭyagṛha). A verse of this chapter says about the possible defects that can occur in column installation.

> stambhasyotthāpanesamyagdoṣāhyeteprakīrtitāḥ |
> acalaṃcāpyakampañcatathaivāvalitaṃpunaḥ|| NS 2:55

Literal translation: *The columns shall be erected without any defects. It shall be fixed, without vibration and without eccentricity from position.*

Requirements of structurally sound column are identified as

i. Fixity
ii. No buckling and consequent vibration, (slenderness ratio.>12)
iii. No Eccentricity

5.2.1 Columns in Multi-storeyed Construction

Multistoried buildings are also dealt with in Vāstu texts. The maximum number of floors specified is in the range of 12 floors.

The main building in a temple where deity is housed is known as Prāsāda. Maximum of twelve (12) floors is recommended for a Prāsāda. Maximum overall height recommended is 100 Hasta (72*m*). Incidentally, it may be noted that the unit of measurement in Vāstu is Aṅgula (A) which is equivalent to 300 *mm* and 12A makes a Vitasthi (V) which will be 3600 *mm* and 2 V make a Hasta (H) which is equivalent to 7200 *mm*. It is mentioned that more than that height can cause damages due to wind and other natural forces. *Bṛhatsaṃhitā* written by Varāhamihira (585CE) also states the same limit. Corresponding to this height the width recommended is 70H (50.4 *m.*), *Mayamata* (Chapter11). For evidently this will ensure 'no tension' at the base.

Here it is pertinent to note that an upper limit is required for structures, because when height crosses roughly 70 *m*, there is a need for 'Dynamic analyses from Wind and Earthquake point of view. The characteristic configuration, simple geometric form of the Indian temple has increased structural strength against earthquake movements (Vasudha, 2004).Interestingly the maximum height among the 15 tall Gopuras and Vimānas existing is exactly 100 H or 72 *m* (216*ft*). Another interesting and noteworthy point is that all these towers are situated in a low seismic zone (Zone: II) as per 1893. Only one or two are in the border of Zone-III. Refer Fig 5.3 showing the location of tall buildings in ancient India.

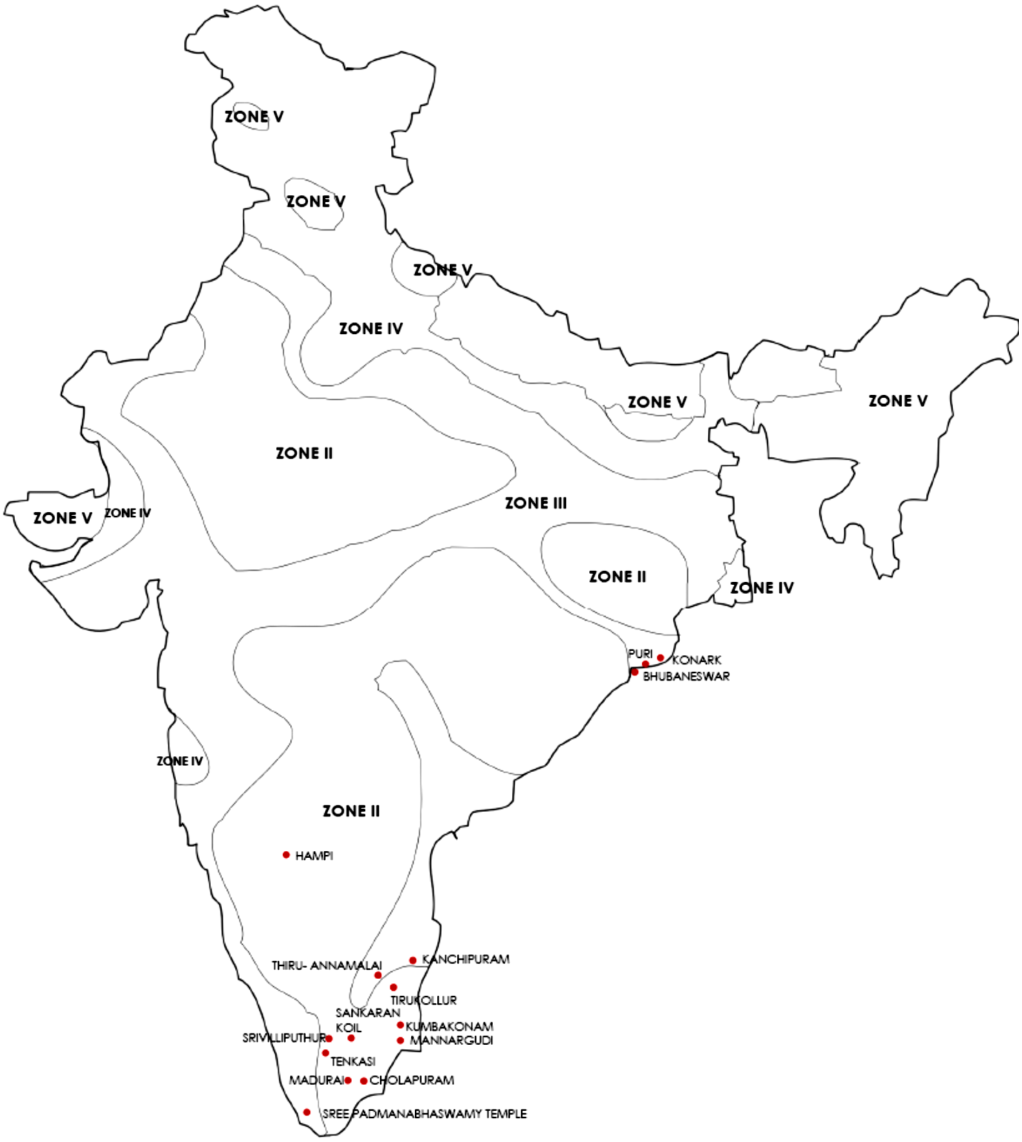


Fig. 5.3 Distribution of Gopurams with respect to earthquake zones

For carrying heavy load transferred from upper floors, for the column in the bottom most floors it is recommended to provide 840 *mm* size (SR: Verse 25:28, 26:28 and 27:28).

Table 5.1. Column dimensions in different floors

Floor	1	2	3	4	5	6	7	8	9	10	11	12
Column Size	28A	26A	24A	22A	20A	18A	16A	14A	12A	10A	8A	8A
	840 mm	780 mm	720 mm	660 mm	600 mm	540 mm	480 mm	420 mm	360 mm	300 mm	240 mm	240 mm

The size of column shall be 8A (24 *cm*) minimum and it shall be increased by ½ A (1.5 *cm*) up to 9 or 10 A (30 *cm*). Accordingly, for 8H (576*cm*) the size will 48 *cm*. The Maximum size mentioned in SR is 84 *cm*.

When there is restriction to limit the column size while ensuring L/D ratio less than 12 there will be restriction to height. Then how to provide more head room where requirement warrants is also addressed by the Vāstu texts. When height of Pillar is more MC recommends pedestal or wall to reduce effective height of column.

> atyucceṅghrau tu tattatyadhicaraṇadaladvighnavistāramāsū-
> roccoccādhyadhatuṅgaṃ racayatu caraṇaṃ kutracinmadhyatodhaḥ|
> kuryād evaṃ śilābhiḥ praṇigaditasudhābhedasaṃmelitābhir-
> yadvāsāreṣṭikābhiḥ kvacid akhilasamutsedhamardhocchrayaṃ vā || MC 5:27

Literal translation: *For very high pillars the height equal to one and half the height of the basement or in some portion below the middle should be made with width equal to 1 ¼ or 1 ½ times the usual width. This is done to a height 1 ½ times its prescribed width. Alternatively, for the entire bottom half the width is increased in such cases the bottom portion can be made with stone masonry or brick masonry. Also, the entire stone or brick if it is deemed necessary* (Achyuthan and Prabhu, 1998).

The height of columns in Maṇḍapa (Square Pavilion in the front of Temple for carrying out certain rituals) shall be 2 ½ H (180 *cm*) to 8H (576*cm*) with an increment of 6A (18 *cm*) or 3A. Recommended spacing between the columns is 2 H (144 *cm*) to 5 H (360 *cm*). When decorated columns (architecturally treated) the spacing shall be generally adopted 2H (144*cm*) to 4 (288*cm*) The height of columns in Maṇḍapa shall be 2 ½ H (180 *cm*) to 8H (576*cm*) with an increment of 6A (18 *cm*) or 3A.The spacing usually adopted are 2H (, 21/4, 2, 1/2, 23/4, 3, 31/4, 31/2, 33/4, 4, (9 types).

Let us examine the detailing of various structural elements and its analysis and comparison in terms of modern theory.

5.2.2 Oma (The Column Base)

These columns are erected on a strong base made of either hard rock or strong wood according to the material of construction of column. If columns are of stone cut, the base will also be of hard rock. In the case of timber or masonry columns, the base can either be of hard wood or rock. These are called as Oma (Padapīṭha) in Vāstu literature. While fixing the measurements of various structural elements, the top dimension of the column is taken as a unit (module) and is called a Daṇḍa (D_t). According to *Manuṣyālaya Candrikā*,

> Vinyasyet pādapīṭhaṃ sudṛḍhataraśilāsāradārupraklṛtaṃ
> māsūroparyathābdhyaśrakavasunṛpakoṇaṃ kvacid vartulaṃ vā|
> stambhobhāgakarṇonmitavitatatadardhocchrāyaṃ vā tadaṅghrya-
> nyardhāśonaṃ ca padmopamam api kuhacid vā janādyanvitaṃ ca || MC 5:22

Literal translation: *Then, the Padapeeda is made with hard stone or hard wood, square, octagonal or hexa-decagon or in some places circular sections replaced above the basements width equal to the diagonal at the base of the pillar and height equal to half that or one-third, one-fourth or half less than that resembling lotus flower and sometimes with fillet* (Achyuthan and Prabhu, 1998).

The Padapīṭha (oma) made with hard stone or hard wood. The shape adopted are square, octagonal, or sixteen sided or in some places circular. Regarding width, it will be equal to the diagonal at the base of the pillar and height (thickness) equal to the half of the width or one-third, one-fourth or half part less than that. According to SR (Chapter 21), the size of the base (Oma) shall be $2D_t$ (twice the top dimension of the column) and thickness base (Oma) shall be one-fourth of that. *Bhāṣā Śilparatna* another popular text, written in Malayalam states that the base (Oma) will have the shape of the base of the column and size shall be 2 or 3 D_t or diagonal of the base width (D_b). Thickness shall be ½ or ¼ of its lateral columns are placed on the base blocks (Oma) by providing a recess in the base block (Oma) and by providing a key (projection) in the column base. This projection shall be square in shape and size equal to $^1/_3$ of the dimension of the column bottom portion. Manuṣyālaya Candrikā states that,

> stambhāḥ svavistāra hutāśabhāgapraklṛptamūlāgraśikhāsametāḥ |
> sthāpyāyathārhaṃnidapīṭhikordhvaṃ tadgartasaṃlagnaśikhāḥ samastāḥ ||
> MC 5.23

Literal translation: *All Pillars with square tenons of width equal to one –third of own width should be placed above their own oma (Base-block) with said tenons joined with their own mortises.*

> vyāsārdhādhikadīrghaṃ pādonāḍhyaṃ tathaiva netraghnaṃ |
> dhūrdhūraprasāvābhaṃ kūṭaṃ kuryād adhomukhaṃ niyatam || SR 21:54)

Literal translation: *The column projection shall have diameter* $^3/_4$ *of bottom size or* $^4/_5$ *of bottom size.*

These projections act as shear connectors preventing the column from sliding in any direction.

Analysing from structural point of view it can be seen that the Base block is intended to keep the column in position and the same time to transfer the vertical load from column to the ground by distributing to more area. The Column is connected to the base block only through a tenon (key). This kind of connection will ensure that column is held in position without transfer of any moment. Thus, it becomes equivalent to hinged connection. This is essentially required since there no structural foundation available to carry any moment.

As stated above, the minimum lateral dimension of the block specified is $\sqrt{2D_b}$ and hence the minimum area that will distribute will be twice the area of the column and hence the stress will be reduced to half. The maximum size specified is $3D_t$ and hence stress below the base block will be approximately 1/7 of the column stress at bottom dimension as D_t varies from $5/6$ to $11/12$ of D_b.

If P is the load on the column, stress below base block (oma) *(p)* will be

$$A = 3(D_t)^2 = \frac{121}{16}(D_b)^2 \quad \text{......} \quad (1)$$

$$\therefore \; p = P/A = \frac{16P}{121(D_b)^2} \quad \text{......} \quad (2)$$

The maximum projection from face of column will be:

$$x = \frac{1}{2}\left(\frac{33}{12}D_b - D_b\right) = \frac{21}{24}D_b \text{ .... (3)}$$

$$\because D_t = \frac{11}{12}.D_b \text{ .... (4)}$$

Bending moment $M = \frac{px^2}{2} = \frac{49P}{968}$

Required thickness:

$$t = \sqrt{\frac{6M}{f_t}} = \sqrt{\frac{147P}{242\,ft}} \text{ .... (5)}$$

Also

$$fc = \frac{P}{(D_b)^2}$$

$$W = 3D_t$$

$$t = D_s\sqrt{\frac{147\,f_c}{242\,f_t}} = D_t\sqrt{\frac{0.6\,fc}{ft}} = \frac{W}{4}\sqrt{\frac{f_c}{f_t}} \text{ .... (6)}$$

The specified thickness varies from $W/4$ to $W/2$. Thus for materials like timber when $fc/ft \approx 1$, $W/4$ shall be adopted and for stone where $fc/ft \approx 5$. Thus, the specification and practice followed are perfectly matching with the stress analysis results using modern theory.

The minimum size of base-block (W) specified is 1.414 D_b. In such case, when minimum thickness of W/4 considered, projection will be 0.212 D_b, which have dispersion angle (α) roughly 45º.

$$\alpha = \tan^{-1}\left(\frac{0.25}{0.22}\right) = 48.65°$$

As per the clause 34.1.3 of IS 456:2000, in the case of plain concrete pedestals, the angle between the plane passing through the bottom edge of the pedestal and the corresponding junction edge of the column with pedestal and the horizontal plane shall be governed by the expression:

$$\tan\alpha \leq 0.9\sqrt{\frac{100p}{fck}+1}$$

Where p = calculated maximum bearing pressure at the base of the pedestal in N/mm^2, and f_{ck} = characteristic strength of concrete at 28 days expressed in *N/mm^2*.

Assuming that column is stressed to its ultimate capacity, we have

$$\tan\alpha \leq 0.9\sqrt{\frac{100p}{fck}+1} = 0.9.\sqrt{\frac{2P}{.D_b^{\ 2}},\frac{D_b^{\ 2}}{P}+1} = 1.55 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

$$\therefore \alpha = 57°10' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

5.2.3 Potikā (Column Capital)

Potikā is a structural element provided at the top of column on to which the beam is placed. This Potikā will ensure proper connection between the column and beam and also will evade chance of shear failure at the column beam junction. These Potikās are also architecturally treated and based on the size bear different names. The Potikā width (W) same as bottom width of the column is Uttama (Superior), same at middle width Madhyama (Medium) and top width Adhama (Inferior).

> tadūrdhve potikāṃ kuryānnānābhedavicitritām|
> pādamūlasamavyāsāpotikāparamuttamā||
> pādamadhyaviśālenasamavyāsācamadhyamā|
> agrapādaviśālasyasamākanyasabodhikā|| SR 21.99-100

Literal translation: *The length of the Uttamapotikā shall be 5* D_t *and thickness shall be same as width W. length shall be Madhyamapotikā will have length equal to* $4D_t$ *and it will be having thickness W/2. The Adhama type will have length equal to* $3D_t$ *and minimum thickness of W/3. In another approach Width (W) of Pothika shall be size of column at bottom, middle or at top. Length 3Dt, 3.5Dt, 4Dt, 5 Dt Thickness shall be W, W/2, 2/3W, 4/5 W, 3/5W, 3/4 W.*

From structural point view also, in order to resist shear force, it is always desirable to provide a column capital. These Potikās are fixed on the columns by means of shear keys provided at the top of the column as in the case of Oma. Then the wall plates/ beams are fixed to Potikā by means of wooden keys having size one-third of the width of the Potikā.

5.3 DESIGN OF WALL PLATES /BEAMS

Dimensioning of various types of wall plates are given below.

> stambhamūlasamaṃ tāraṃ tārāsyārdhaṃ ghanaṃ viduḥ |
> saptāṃśāśugabhāgaṃ vātithyaṃśerudrabhāgikam ||
> navabhāgaṣaḍaṃśaṃ vā rudrāṃśesaptabhāgikam |
> evaṃ pañcavidhaṃ proktaṃ rūpottaraghanaṃ budhaiḥ || SR 29.2-3
> patrottarasyavistārāt tribhāgaṃ ghanamānakam |
> ṣaḍbhakteghanamānenāpyagnibhāgaṃghanaṃviduḥ || SR 29.4

Literal translation: *The wall plate shall be of width same as that of column base (D_b) and depth same as that depth is called Khaṇḍottara. And depth equal to ¾ of D_b is called Patrottara and ½ of D_b is called Rūpottara. The Patrottara will have depth equal to one-third of the width. The Kambu will be one sixth of the depth.*

This Khaṇḍottara is recommended for all major structures (SR: 29:1-4). The Depth of Rūpottara is fixed as D_b/2 or 5/8 of D_b, 11/15, 6/9, 7/11. Thus, Patrottara will have depth equal to w/3.

Manuṣyālaya Candrikā says:

> stambhād hastārabhedaprakathanavidhinaivottarāṇāṃ ca tāraṃ
> khābhīṣṭaṃ kalpayed vā vasuvasuyugalārkormisaṅkhyāṅgulairvā|
> śreṣṭhaṃ khaṇḍottaraṃ tadvitatisamaghanaṃ madhyamaṃ patrasaṃjñaṃ
> pādonoccaṃkaniṣṭhaṃvitatidalaghanaṃtatturūpottarākhyam || MC 5:31

Literal translation: *The width of the uttaras should be decided by the rule mentioned for the bottom width of the pillars or as 6,8,12 or 16 angulas. That with thickness equal to its* *width is the auspicious khandottara, that with thickness equal to three-fourth the width is called Patrottara and is medium and that with thickness equal to half the width is called rupottara and is inferior.*

Here it may be noted that beam width is kept same as the column width at base and depth is altered depending up on the requirement. For major structures, square beams are recommended. From structural point it is economical to have more depth than width since moment carrying capacity is proportional to the square of the depth. Then why, a square beam is recommended? In order to have proper connection between the column and beam the width of the slightly more than the top width of the column is a practical requirement. More over these beams are of timber construction, hence structurally more depth will not produce more carrying capacity since stress decreases when distance between outer fibre from the Neutral axis increases (Sheikh and Ahmad,2015) In order to compensate this reduction, usually a term called form factor is applied.

The 'form factor', $K = 0.81\left(\dfrac{d^2 + 894}{d^2 + 550}\right)$ when d depth of beam is taken in cm and D>30cm (Reference code IS 803)

As stated earlier the beam span will not be more than the column height and hence span /depth ratio of the beams also will same as that of column. Let us analyze this using modern theory.

Here let the span of beam $= l$

The maximum deflection, δ in a uniformly loaded beam will be as follows.

$$\delta = \frac{5}{384}\frac{wl^4}{EI} = \frac{5}{384}.\left(\frac{wl^2}{8}\right)\frac{8l^2}{EI} = \frac{40}{384}\left(\frac{Ml^2}{EI}\right) \text{ ....} \quad (1)$$

$$\delta = \frac{40}{384}\left(\frac{Ml^2}{EI}\right) = \frac{40}{384}\left(\frac{M}{I}\right)\left(\frac{l^2}{E}\right) = \frac{40}{384}\left(\frac{2f}{d}\right)\left(\frac{l^2}{E}\right) \text{ ....} \quad (2)$$

$$\delta = \left(\frac{80f}{384E}\right)\left(\frac{l^2}{d^2}\right) = \frac{5}{24}\frac{f}{E}\frac{l^2}{d} \text{ ....} \quad (3)$$

$$\therefore \frac{l^2}{d} = \frac{24E\delta}{5f} \text{ ....} \quad (4)$$

Where f allowable stress is in bending and E is modulus of elasticity.

But in the case of timber beams, maximum deflection allowed is $\frac{l}{240}$.(IS 803)

$$\therefore \frac{l}{d} = \frac{E}{50f} \text{ ....} \quad (5)$$

For timber beams, say Teak wood considering the stresses (Vazrani and Ratwani 1995)

$$f = 14N/mm^2$$
$$E = 9600N/mm^2$$

Using Eq. (5) $\frac{l}{d} = \frac{9600}{14 \times 50} = 13.71$

The traditional texts have fixed this ratio conservatively as 12 and have set the maximum value as 16 (Reference: SR) i.e. 50 % higher as in most cases the actual stress will be less than the allowable stress. In the above case, actual stress corresponding to the maximum l/d of 16 works out to 600 N/mm2 which is very reasonable and practical and will be able to limit deflection as IS 893:1994.

5.3.1 Chittutharam (Sub Beam)

In order to receive the rafters, above the beam or wall plate, a sub beam is place. This will ensure that main beam is bot cut or tampered for fixing rafters. These sub-beams are called 'chittutharam'. The W or 3/4 W of Beam shall be height of Chittutharam. 1/2, 3/4, 1/3 shall be thickness. The chittutharam will receive the rafters. By providing verticals at intervals and providing a member at the top of the verticals, this chittutharam are sometimes replaced by a truss like structure also.

These verticals or stud columns are called Chuzhikakkal and the same will have minimum height equal to the width of Chuzhika or 1 A more. This can be increased by 1 A as desired. The stud thickness shall be same as that of Chuzhika. The width shall be 2, 3 or 4 times the thickness. The Chuzhika shall be fixed over the Chuzhikakkal (Studs). The Chuzhika can be fixed directly to the Uttara by proper nails also. (SR 29.19-21).

5.3.2 Rafters

The arrangement of rafters in traditional style is different from the current practice of providing hip rafters and jack rafters from the hip rafters (Refer Fig. 5.4). In the case of rectangular room, the main rafters (common rafter) that are connected perpendicular to the ridge-piece is called 'prakṛtilūpa' or main rafters. On either side connecting to the ends of the ridge-piece there will slanting rafters which are called ‘vikṛtilūpa’. Accordingly, in a square pavilion (Caturamaṇḍapa), all the rafters will be slanting or Vikṛti. Usually the pitch adopted in traditional buildings is ½. However, various pitch between 1/2 to 1/3 are also recommended.

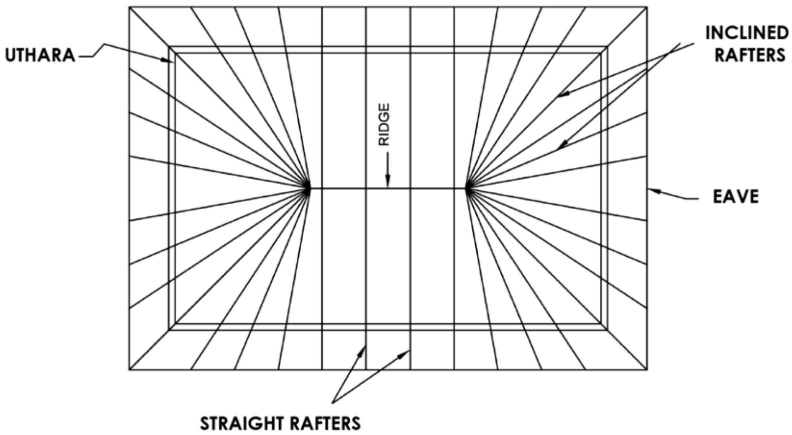


Fig. 5.4 Rafters in traditional buildings

For the calculation of the length of the rafter both graphical and analytical method are suggested. For calculating analytically, the length of the common rafter using the property of right triangle is used. The relationship between the sides and hypotenuse of the right triangle (Pythagoras theorem-c.500BCE) is known as Bhuja-Koṭi-Karṇa-Nyāya and is known in India from Vedic age (Rajasekhar, 2018). *Āpastambasūlbasūtra* (1000BCE) mentions this relationship (Stall, 1999). The *Silparatna* says to add the square of the half width to the desired height of the roof and to take square root to get the length of the common rafter. For the slant rafter (Vikṛti), sum the squares of the half the width, desired height and the distance of the rafter from the entre point of the width and then take the square root to get the length of the vikṛtilūpa. (Reference SR: 33:1- 5) (Refer Fig. 5.5).

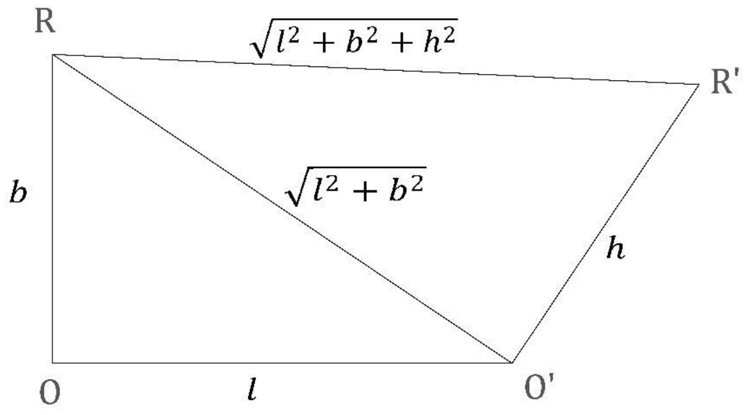


Fig 5.5 Graphical determination of length of Vikṛtilūpa

$$L_p = \sqrt{\left(\frac{W}{2}\right)^2 + H^2}$$

$$L_v = \sqrt{\left(\frac{W}{2}\right)^2 + H^2 + D^2}$$

The size (width and thickness) rafters shall be proportional to size of the wall plate or beam. Usually the width (depth) kept same as the width of beam or higher by adding 1/4, 1/2, 3/8 of beam width. The thickness shall be half the height of the rafter as per the following verse in Śilparatna.

> ardhatulyaṃ tu bāhalyaṃ lūpānāṃ yavavṛddhitaḥ|
>
> yāvadṛtvaṅgulaṃ tāvat kuryādaucityabhedataḥ || SR 32:10

Literal translation: *The thickness of rafter shall be half of its width and it can be thicker in increment with an increment of one yava.*

From the above it can be seen than when rafter depth provided is same as that of wall plate/beam width, its l/d ratio also will be in the same ratio. Hence maximum span allowed will same as spacing between the columns. Hence when span is more than l, another beam is introduced to break the span and this is called 'Ārūḍhottara'. This 'Ārūḍhottara' is supported by a strut from the main beam and this member is called 'kodungakkal'. Then cross beams are also provided. Then central span of the rafter will be limited to l and also maximum. This arrangement of Ārūḍhottara is similar to a truss (Vierendeel truss) (Refer Fig. 5.6).

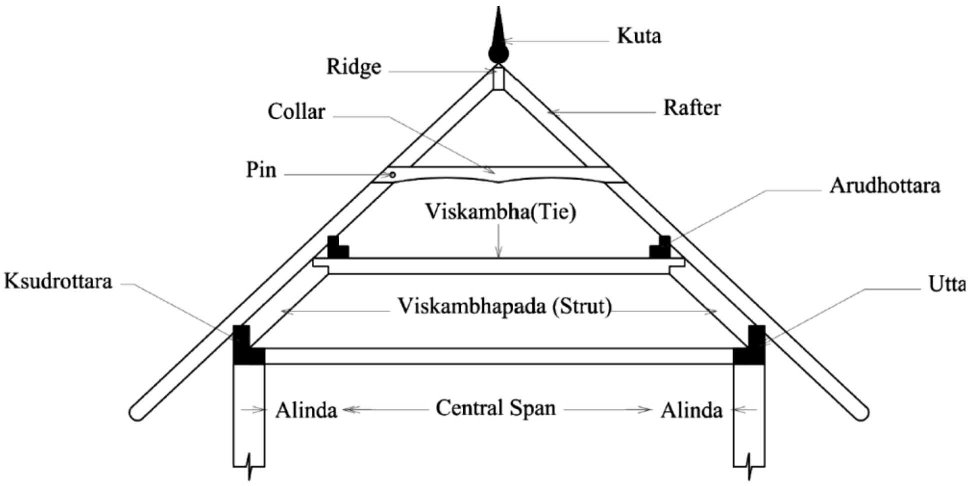


Fig. 5.6 Ārūḍhottara with different parts of timber roof elements

Horizontal distance between Ārūḍhottara and main beam will be l/2. In such case maximum span of the building will twice the spacing of the column or twice the height of the column. Verticals are also provided for strength between the cross beams at bottom and top as shown in the sketch.

Collar pins introduced between the rafters are called vala. These are provided at bottom as well as at middle-third height. At middle third height collar also will be provided as shown in the sketch. When compared to modern practice the collar is the main member and collar pin is an only member connecting rafters. However, in traditional construction, the Vala or Pin is primary.

Providing collar pin in the slanting rafter is a challenge since the hole to be cut is three –dimensional. If we closely examine any old structure, it can be inferred that this has been achieved perfectly by carpenters with their mathematical and carving skills

These rafters will be usually tied by providing another square wooden piece, which is locally Vala. These wooden pins pass through the rafters, and hence there should be holes (slots) to receive these pins. The outer most line of rafters is called eave (Vamata.)

These pins or Valas are provided in different shapes to show the mathematical precision and skills of 'Sthāpati' by providing in the shape of 'Crescent of Moon (Candravala) etc.

5.4 RIDGE PIECE

The height shall be ½ or 3/4th width of all wall plate/beam. The width shall be either same as that of height or half of height. For large spans, these ridge pieces are supported from the cross beams provided between the main beams.

5.5 CURVED CORRIDOR

In Vaikom Mahadeva temple, there is a corridor from Kinattupura (the building that houses the holy Well, Manikkinar, inside the temple) and the Sopanam, the holy steps to the sanctum sanctorum. This corridor is curved in geometry and hence curved beams (wooden) are provided above stone columns (pillars). The notable point in the structure is that out of 8 columns, 5 columns are smaller in size and 3 are slightly bigger compared to other columns. Interestingly central columns on both sides are smaller in size. The remarkable point in this is that the columns that are having higher size are the ones subjected to more loads from Dead, Live and Wind load cases when analysed using STAADPRO software. These testimonies that the unknown Engineer (c.1525) who designed it, had ample structural concept to assess the variation of loads due to a curved geometry.

5.6 CONCLUSION

From the above discussions, it could be inferred that much thought process regarding the aspects of structural engineering had taken place in Vāstu tradition too. Setting a range for slenderness ratio for columns which astonishingly matches with the current code provisions is a commendable achievement. Vāstu texts also reveal that through rational approach and systematic research, they were able to anticipate some structural engineering theories prior to the emergence of modern structural Engineering. Also the same rational approach is adopted in detailing various structural elements in the traditional architecture.

Vāstu has scientifically developed taking into consideration, all the required aspects such as strength and utility. Moreover, by adopting a modular concept, optimum use of materials and their re-use was ensured. By setting an inter-relation in the sizing of columns, beams, rafters, ridge piece etc. the wood cutting was made easy with maximum utility (Jose and Rajasekhar, 2018).

CHAPTER 6

SPECIAL STRUCTURES IN VĀSTU

6.1 INTRODUCTION

Nāṭyagṛha (Theatres), Prāsāda (Main Temple tower), Gopura (Entrance Tower), Dvajastabha (Flag posts) etc. are mainly the special structures which requires detailed study. Of these Nāṭyagṛha or theatre structures, has uniqueness. In Kerala, there exists, Koothamblalam functionally same as Nāṭyagṛha in many major temple complexes. But differs from Bharata's concept in many aspects. But Bharata has dealt the subject in detail. This chapter mainly deals with Bharata's views on Theatre structures and attempts to decode certain grey areas and analyses the science behind his specifications.

Amphitheatres with a gallery arrangement that existed in Greece and Rome around c.100 BCE is a great surprise to Architects and Engineers. These structures had inspired medieval Architects and thus prior to the era of indoor play-houses and opera houses, many outdoor theatres were built in Europe. It is only after renaissance, at the beginning of 17th century, theatres moved indoors and began to resemble the arrangement that is familiar to us now with a stage separated from the audience. The first opera house open to the public was built in 1637 CE (Teatro San Cassiano) in Venice. This was the model for the subsequent theatres throughout Europe. The design details of the classical theatres that evolved during after 17th Cent are described in the Architect's Data (2012).

6.2 DESIGN OF NĀṬYAGṚHAS

According to Architect's Data (2012), the classical theatre geometry has been derived from following visual considerations.

"*Proportions of the Classical, auditorium: (Opera, multipurpose Theatre, traditional play house), the maximum distance of last row from the proscenium line (start of stage):*

For play house: 24m (maximum distance from which it is still possible to recognize facial expressions);

For opera houses: 32 m (Important movements are still recognizable); Width of auditorium:

Going through *Nāṭyaśāstra* written by Bharata (c.300 BCE), it is astonishing that almost the same numbers have been mentioned clearly for fixing the size of auditorium and stage which makes us to believe that it is not just a coincidence, but as an outcome of scientific thought and rational thinking.

Table 6.1 Comparison between classical theatre and Nāṭyagṛha

Parameter	**Architect's data Book**	***Nāṭyaśāstra***	**Remarks**
Length of Auditorium	24 *m*	23.04m (32 H)	The max. Distance at which the facial expressions are clear as per both texts.
Width of Proscenium	12.85 *m*	11.52 (16 H)	For easiness of computation NS has taken (α =28 degrees) instead of α =30 degrees, slightly small value as so that tan α =0.25.
Width of auditorium	25.7 *m*	23.04m (32 H)	
Setting out point 'p'	48 *m*	46.08 m (64H)	

Thus rectangular theatre in NS is perfectly matching with classical theatre design rules. On detailed analysis it could be seen that, for easiness of computation NS has taken (α ~28 degrees instead of α =30 degrees in Architect's Guide) slightly smaller value so that tan α =0.25. Here it is pertinent to note that the similarities in the results make us presume that the concept of 'vision triangle' was known to the author of NS also. The suggestion to construct a triangular Theatre seems to be direct adoption from this vision triangle.

> pramāṇaṃ yacca nirdiṣṭaṃ lakṣaṇaṃ viśvakarmaṇā |
> prekṣāgṛhāṇāṃ sarveṣāṃ taccaiva hi nibodhata || NS:2:9

Literal translation: *The specifications and measurements of theatures that are expounded by Viswakarma are here presented for your understanding*.

> aṇū rajaśca vālaśca likṣā yūkā yavastathā |
> aṅgulaṃ tathā hasto daṇḍaścaiva prakīrttitaḥ || NS :2:10

Literal translation: *Anu, Reja,Vala, Liksha,Yuka, Yava , Angula, Hasta and Danda are the measuring units*.

> aṇavoƒṣṭau rajaḥ proktaṃ tānyaṣṭau vāla ucyate |
> vālāstvaṣṭau bhavellikṣā yūkā likṣāṣṭakaṃ bhavet ||
> yūkātvaṣṭau yavo jñeyo yavātvaṣṭau tathāṅgulam |
> aṅgulāni tathā hastaścaturviṃśatirucyate ||
> caturhasto bhaveddaṇḍo nirdiṣṭa stu pramāṇataḥ |
> anenaiva pramāṇena vakṣyāmyeṣāṃ vinirṇayam || NS 2:11

Literal translation: *Eight Anu will be a Reja . That eight will form a Vala. Eight Vala will be Liksha and Yuka is eight Liksha. Eight Yuka is one Yava, and eight Yava is one*

Angula. Twenty four Angula will make a Hasta and four Hastas will make one Danda Thus one Hasta (H) will be equivalent to 72 cm. The sizes mentioned in terms of Hasta.

The length of the hall shall not be more than 64 H (45.8 *m)* and its width shall be 32 H (22.9*m*), the reason is very clearly given in the following verse. If dimensions are more than this, the performance will not be clearly visible to the viewer. If length is more, the dialogues and music will not be clear because of 'double sound' or echo. *Nāṭyaśāstra* says:

> prekṣāgṛhāṇāṃ sarveṣāṃ praśastaṃ madhyamaṃ smṛtam|
> tatra pāṭhyaṃ ca geyaṃ ca sukhaśrāvyataraṃ bhavet || NS:2:16

Literal translation: *Among all the theatures, the medium size is advisable. There the dialogues and music will be properly perceptible.*

It is mentioned that if medium size is adopted, both "Pāṭhyam"and "Geyam" will be heard very clearly. The differentiation between Pāṭhyam (dialogues or speeches) and Geyam (music) is noteworthy from acoustic point of view. Though both are sounds, their requirements are different for audio clarity requirements. In modern terms, acoustics requirements of a lecture hall and concert hall are different. According to modern acoustics (Knudsen and Harris, 1980), the reverberation time controls the quality of sound. *'The 'reverberation time' of a space changes the way the space 'sounds' and can affect the intelligibility of acoustic information. A high reverberation time can make a room sound muffled, loud and noisy. Rooms designed for speech typically have a low reverberation time, whereas a higher reverberation time can add depth, richness and warmth to music. The reverberation time of a room is defined as the time it takes for sound to decay by 60 dB after an abrupt termination. It is linked to the total quantity of soft treatments and the volume of the room*'

Moreover, the facial expressions (Bhāva and Rasa which are very important in Indian theatre) will also not be perceptible. Here the limit is set based on the audio-visual limitations of human beings. The Echo forming length/width is $0.01\times 340m = 34\ m$ and hence allowable length is 17 m from source to obstruction which is also more or less met by adopting the medium size of Nāṭyagṛha (Knudsen and Harris, 1980).

Observations in *Nāṭyaśāstra* reveal that Indians were not only adepts in the design of temples and residential buildings but also experts in the architecture of special structures like auditorium with and without galleries. The peculiarity of auditoriums lies in the fact that it requires a deep knowledge in the physics related to sound and the science behind the formation, propagation and decaying of sound.

Bharata's *Nāṭyaśāstra* though a work of considerable antiquity is still not antiquated with respect to dance and dramaturgy since the theories in NS are still relevant and practiced as in the case of Kudiyattam, Kathakali, and Bharatanatyam etc.. Bharata has dedicated a chapter in *Nāṭyaśāstra*, one of the most ancient texts in the world on dramaturgy, to the design and construction of Nāṭyagṛha or theatre structures. Chapter two comprising of hundred verses is entirely devoted for this topic. Later, most of the commentators of the text who are from the circles of theatre, poetry and drama, have left some room for confusion owing to lack of clarity. This may be due to their unfamiliarity of the subject matter since it belongs to a building science portfolio. Ramakrishnakavi while re-editing the first edition of NS (1926) by who published *Nāṭyaśāstra* from Baroda with the commentary of *Abhinavabhāratī* of Abhinavagupta (c.1000 BCE) has made a following remark.

The second chapter of the text and the commentary has a quite different story to tell. Unfortunately the manuscripts of this chapter have presented many omissions, several incorrect readings and much confusion. This chapter relates to the construction of theatres for the dramatic performance and its subject matter which is highly scientific and technical has baffled even Abhinavagupta.. Every commentator and critic has failed to present an unambiguous text of Bharata and therefore to present a clear meaning from the text of the NS. or from Abhinava's commentary which has itself advanced many views and created considerable confusion'. (Ramakrishnakavi, 1956).

Either because of unfamiliarity with engineering knowledge among Sanskrit scholars or lack of expertise in deciphering ancient scientific literature among engineers, there have been many ambiguous interpretations on Chapter 2 of *Nāṭyaśāstra* in the modern period also. One of the renowned commentaries on *Nāṭyaśāstra* is *Abhinavabhāratī* by Abhinavagupta (c. 950-1016 CE) who is a dramatist, poet and exegete from Kashmir. In modern period, many translations have been published referring to original text and commentaries. Another scholarly work is available in (Pisharody, 1990) in Malayalam.

A commentary in English by Subba Rao (1956) is also appended in second edition of Baroda publication. From literature it is understood that a good interpretation which could be tried practically has not yet been published. In this context, an attempt is made here to do so. Certain verses are left out since they are not directly connected with design and engineering of theaters. From the contents, it is very clear that Bharata has followed Vāstuśāstra for the basic design and has incorporated certain special requirements which any auditoriums warrant.

6.2.1 Shape and size of theatre structures

According to *Nāṭyaśāstra*, Viswakarma, the divine Architect to whom the text *Viśvakarmīyam* is attributed, after much thought process has come up with three types of Nāṭyagṛha or Theatre structures. The interesting fact is that the *Viśvakarmīyam* or the *Viśvakarmavāstuśāstram* also has a chapter on theatre structures (Sastri, 1990).

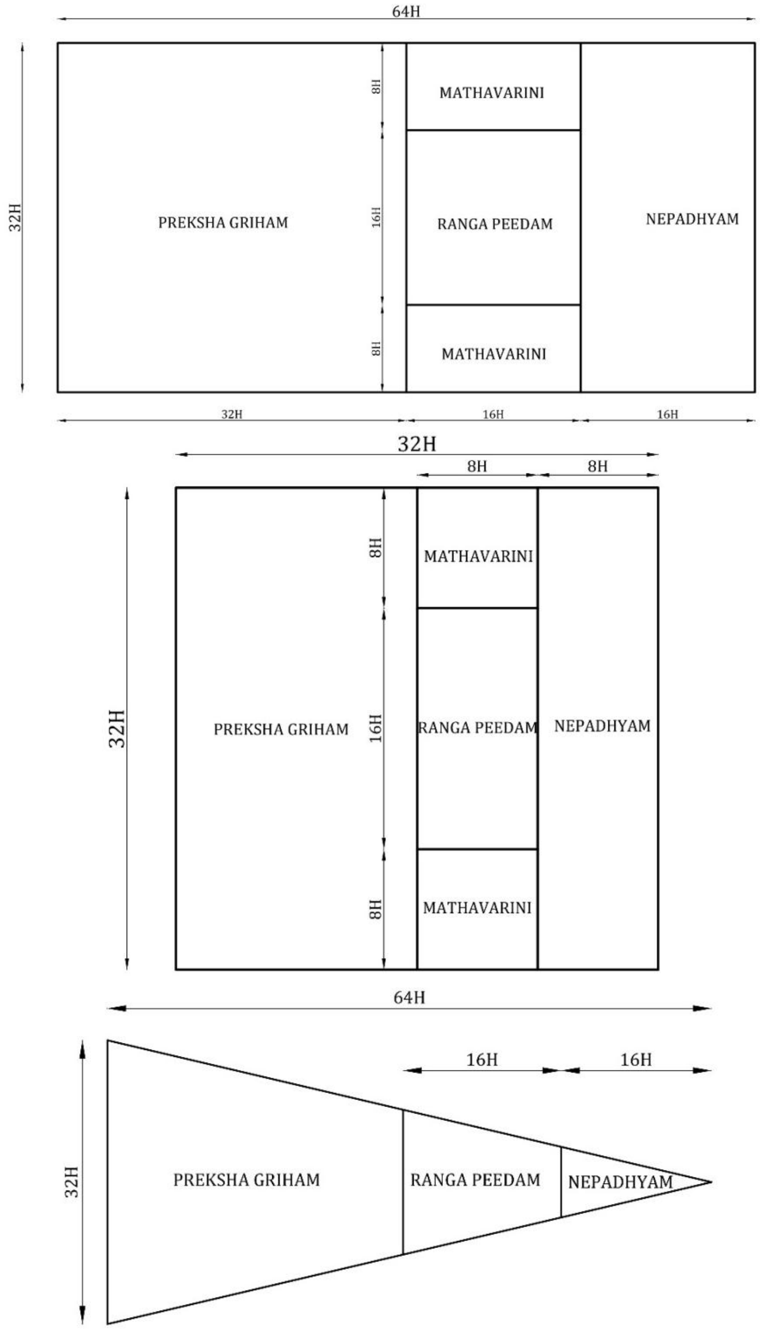


Fig. 6.1 (a) Vikṛṣṭa (b) Catura (c) Tryaśra

The three shapes recommended for nāṭyamaṇḍapa (Theatre structure) are Rectangle, Square and Triangle (Refer Fig. 6.1).

> prekṣāgṛhāṇāṃ sarveṣāṃ triprākaro vidhiḥ smṛtaḥ|
> vikṛṣṭaścaturasraśca tryasraścaiva prayoktṛbhiḥ ||NS:2:5

Literal translation: *The theatures are of three types. They are rectangular, square and triangular*.

Here it is pertinent to note that the mathematics behind different geometrical shapes was very well known to ancient India from the Vedic times. The *Śūlbasūtras* which form an addendum to *Ṛg* and *Yajur* Veda deal with geometry in detail to aid the construction of Vedic Altars (Kulkarni, 1983). Mainly four *Śūlbasūtras* namely Baudhāyana, *Āpastamba, Kātyāyana* and *Mānava* are considered important. The Altars or the vedis for the Yajña, are sometimes of very complicated shape as 'Falcon' (svenaciti). So also the intrinsic geometry was needed for scribing the shape and for pre-engineering bricks for forming these shapes (Kulkarni, 1987). Thus it became a necessity for them discover, the relation of sides of right triangles, triplets extraction of irrational roots of rational numbers known as Karani etc. (Rajasekhar, 2018). The relation of Bhuja–Koṭi-Karṇa Nyāya (presently known after Pythagoras (c.550BCE), the Greek philosopher) is seen in *Āpastambasūlbasūtra* (AS) (Srinivasachar, 1931).

dīrghacaturaśrasyākṣṇyā rajjuḥ pārśvamānī tiryagmānī ca yat pṛthakbhūte kurūtastadubhayaṃ karoti | AS

Literal translation: *A rope stretched along the length of the diagonal produces an area which the vertical and horizontal sides make together*.

Irrational roots of rational numbers

In *Baudhāyanaśūlbasūtra* as well as in *Āpastambaśūlbasūtra* gives the length of the diagonal of a square in terms of its sides, which is equivalent to a formula for the square root of 2:

samasya dvikarāṇi pramāṇaṃ tṛtīyena vardhayet
taccaturthenātmacatustriṃśoƒnena saviśeṣaḥ|

Literal translation: *For the diagonal of a square the measure is to be increased by a third and by a fourth decreased by the 34th*.

That is its diagonal approximately, which will yield the value of $\sqrt{2}$ as follows:

$$\sqrt{2} \approx 1 + \frac{1}{3} + \frac{1}{3.4} - \frac{1}{3.4.34} = \frac{577}{408} = 1.414216..$$

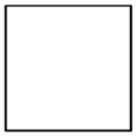
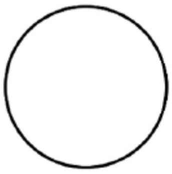
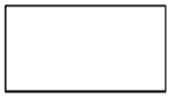
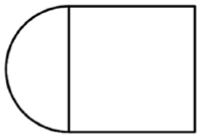
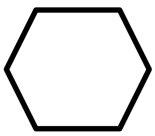
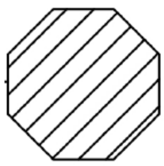
(Correct up to 5 decimal places.)

Here it is worthy to note that circular shapes, semicircular shapes etc. are excluded, though these shapes were familiar and used in construction. For Prasadas (palatial buildings) the geometry used are rectangle, square, combinations of semicircles with rectangle. *Tantrasamuccaya* gives the rule as follows for different shapes (Kannippayyur, 2003).

'*From the desired perimeter, the radius for scribing the circle can be obtained by dividing perimeter by 710 and then multiplying by 113'*. In short, the value of $\pi = \frac{355}{113}$ is considered (one of the best values in 15th cent., details are discussed elsewhere) incidentally many circular temples are there in Kerala.

For rectangular Prāsādas, Half the perimeter is divided by 10 and four parts is taken as breadth and 6 parts as length. That is the length-breadth ratio will be 3:2, an ardhādhikam ratio in Vāstu proportioning system. Other type is a semicircle mounted on a rectangle. When built with semi-circle in the rear side will resemble a backside of an elephant and hence this shape is called 'Gajapṛṣṭam'. Mulakkulam temple near Piravam is in this shape. Yet another type of Prāsāda is Dīrghavṛtta, with two semicircles on either shorter side of a rectangle. Other two types are hexagonal (ṣaḍśraprāsāda) and octagonal (Aṣṭaśra) (Ramakrishnan, 1998). The geometry and the computational details are given in Table 6.2. This is based on Tantrasamuccaya and Bhāṣāśilparatna (Neekantanasari,1996).

Table 6.2 Different shapes of Prāsādas.

Nomenclature in Sanskrit	**Shape**	**Sketch**	**Calculation of sides (a.b) or radius (r). From given Perimeter P**
Caturaśra	Square		$a = \frac{P}{4}$
Vṛtta	Circular		$r = P\left\langle \frac{113}{710} \right\rangle$ $\pi = \frac{355}{113}$
Dīrghacaturaśra	Rectangular		$l = \left(\frac{P}{10}\right) \times 6$ $b = \left(\frac{P}{10}\right) \times 4$
Gajapṛṣṭa	Square with semicircle at rear side		$a = \left\{P - \left(\frac{P}{64}\right)\right\} \times \frac{4}{18}$ Implied value of $\pi = \frac{22}{17}$
Dīrghavṛtta	Rectangular with semicircles on both side		Radius of Semicircle $r = \left\{P - \left(\frac{P}{64}\right)\right\} \times \frac{4}{18}$ Central rectangle, length $l = \frac{6}{7} \times r$ $\pi = \frac{22}{17}$
Ṣaḍaśra	Hexagonal		$a = \frac{P}{6}$ $D = \left(\frac{2P}{6}\right) \times \frac{13}{15}$
Aṣṭaśra	Octagonal		$D = \frac{3P}{10}$ $a = \frac{5D}{12}$

The above table makes the ancient knowledge in Geometry evident (Saraswathi, 2007). *Mayamata* also mentions about twelve (12) different shapes of palace complexes.

Meaning: Twelve shapes are recommended for palace complex (lay out), the shapes are, square, rectangle, circle, elongated circle, Chariot-shaped, Nadyavarttam, Oval, trapezoidal, Swastika and Mrudangam. Thus it can be seen that there were buildings in shapes other than rectangles and square. However for theatre structures, only three shapes are recommended. Their sizes are also recommended in *Nāṭyaśāstra*.

> pramāṇameṣāṃ nirdiṣṭaṃ hastadaṇḍasamāśrayam |
>
> śataṃ cāṣṭau catuḥṣaṣṭirhastā dvātiṃraśadeva ca || NS 2:6

Literal translations: *The sizes of theatures are depended upon measuring rod Hasta and the measurements are 108, 64 and 32 Hastas.*

> aṣṭādhikaṃśataṃjyeṣṭhaṃ catuṣaśṭistu madhyamam |
>
> kanīyastu tathā veśma hastā dvātriṃśadiṣyate|| NS 2:7

Literal translations: *The measurement of 108 H is Jyeshtam (Large), 64 H is Madhyamam (medium) and 32 H is Avaram (Small).*

> devānāṃ tu bhavejjyeśṭhaṃ nṛpāṇāṃ madhyamaṃ bhavet |
>
> śeṣāṇāṃ prakṛtīnāṃ tu kanīyaḥ saṃvidhīyate || NS2:8

Literal translations*: For Devas the large size, for Kings the medium size and for the rest, the small size is recommended.*

Depending on the measurement scale, the three dimensions are 108 Hastas, 64 Hastas and 32 Hastas and these are classified as Jyeṣṭham (long), Madhyam (medium) and Kaniṣṭham (short). Thus, there are three shapes and three dimensions hence total combinations are $3 \times 3=9$. In this context, Hasta daṇḍasamāsrayam could be interpreted as 108 Daṇḍa, 64 Daṇḍa and 32 Daṇḍa also and since 1Daṇḍa is 4 Hastas, another set could be formed which will result in another 9 numbers and hence 18 possibilities are there for Nāṭyagṛha (Pisharody, 1990). This contradicts verse 12 regarding the maximum size as 64H specified based on a valid reason which is explained under the verse. Even if the least of the above three Daṇḍa measurements are considered, i.e. 32D=128 H, which exceeds 64 H. Hence from engineering point of only 9 possibilities need be considered and *'Hastadaṇḍa'* shall be taken as a single word synonymous with *'muzhakkol'* as a measuring scale with one Hasta long.

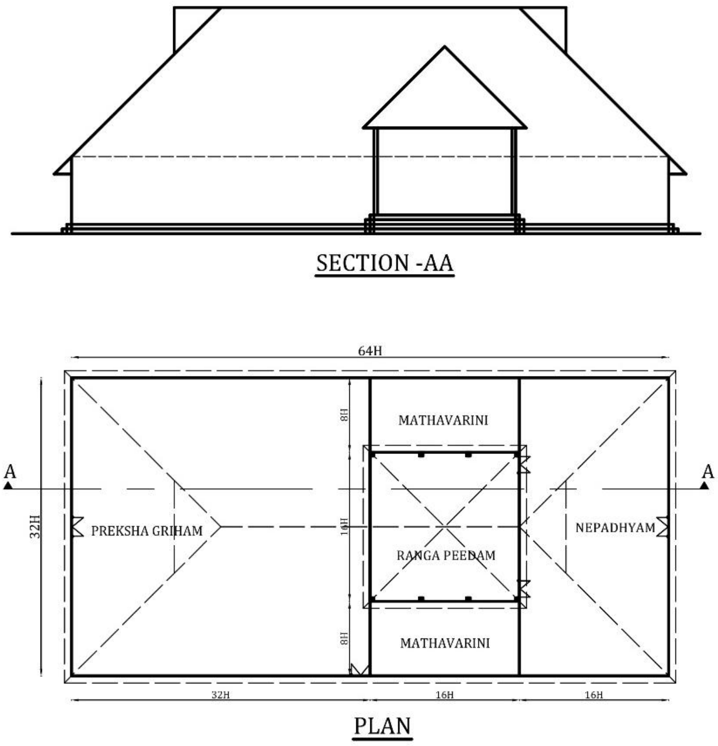


Fig. 6.2 Rectangular Nāṭyagṛha

For Devas, the long one, for Kings the medium and for others the small is suggested. Here also the verse must be read in conjunction with Verse 12. As per the Ernest and Peter, Neufert Architects' Data under 'Proportions of the classical auditorium" recommends the very same with 32m for Opera Halls (The important movements still recognizable). Moreover considering the echo formation, length is 34m considering persistence of hearing as 0.1 *sec* and velocity of sound as 340 *m/sec* (Refer Fig. 6.2).

For Devas, or those who are having more audio-visual abilities, the option of higher sizes can be considered is also implied. It means that with present sound amplification and lighting facilities and of course with acoustic treatments, the higher can be adopted. Finally Bharata stresses again that a medium size will ensure proper audio-visual quality. Of the above, the middle one and the last one are recommended.

Table 6.3 Different shapes and sizes of Nāṭyagṛhas.

Shape / Classification	Rectangular	Square	Triangular (Altitude)
Jyestham	108 H×64H	64H×64H	108H
Madhyamam	64H×32H	32H×32H	64 H
Avaram	32H×16H	16H×16H	32H

The unit of linear measurement adopted in *Nāṭyaśāstra* is in line with the other Vastuvidya texts explained in chapter 1. The Hasta adopted is Kiṣku, one which is widely accepted. The sub units are also given to avoid difference in opinion since the sizing has got not only the aesthetical considerations but have acoustical design criteria. As per the above description, one Aṅgula is 30 *mm* and one Hasta is 72*cm*.

Verses 17 to 25 in the second chapter of *Nāṭyaśāstra* explain site testing and selection which are depicted in other Vāstu texts.

> prathamamṃśodhanaṃ kṛtvā lāṅgalena samtkarṣet |
> asthikīlakapālāni tṛṇagulmāṃśca śodhayet || NS2:20

Literal translation: *After the selection of the land, the site shall be cleared properly and ploughed. After this all debris including roots of grass and shrubs shall be completely removed.*

A levelled ground with compacted and good bearing capacity is cited as a requirement of Nāṭyagṛha. The recommended soil is mixture of white and black soil (verse 19). After site selection, site cleaning is specified and the need for quality control regarding measurement taking is emphasized in 22 lines. Bharata is very much concerned about the attainment of precision of the dimensions specified by him and hence the sage has taken more than five stanzas (22 lines) for ensuring the quality control of the measuring thread or rope. In the text for the Sūtradhāras (directors of play), Bharata is not ready to spare the Sutragrahi (site supervisors) who are responsible for the precise construction of the theatre building where plays are going to be enacted.

Nāṭyaśāstra also mentions about spatial planning. It says:

The theatre of 64 H × 32 H is to be divided in to three. The rear most 16 H × 32 H is for the Nepathya or green room, another 16H × 32 H for the Rangapīṭha (stage) and Mattavāriṇi and 32 H × 32 H is for the Prekṣāgṛha (auditorium). High stage and a level auditorium are recommended for the rectangular theatre.

Regarding the foundation Stone laying Ceremony, it is stated that a ceremonial function on an auspicious day to be conducted for the first stone laying. The system of ceremony detailed indicates that the theatre building is meant for all the four classes of the people and the traces of untouchability and un-approachability which were predominant in the later class structure are not at all seen in *Nāṭyaśāstra*. This also testimonies hat Nāṭyaśāstra is written during Vedic period or post Vedic period.

Being a theatre building, Bharata mentions particularly about the playing of musical instruments and beating of drums suited for the auspicious occasions during the above ceremony.

Erection of Columns:

> stambhānāṃ sthāpanaṃ kāryaṃ puṣpamālāpuraskṛtam|
> ratnadānaiḥ sagodānairvastradānairanalpakaiḥ ||
> stambhasyotthāpane samyagdoṣā hrete prakīrtitāḥ|
> acalaṃ cāpyakampañca tathaivāvalitaṃ punaḥ || NS:2:45

Literal translation: *The columns shall be erected after adorning the same with flower garlands and all and ritualistically. The columns shall be achalam (properly fixed in position), akampam (not vibrating) and askhalith (shall be placed exactly in the position).*

Ritualistic and careful erection of the column in position without any defect is recommended. The defects that can occur for columns identified by the sage reveals the extent to which scientific thought was applied in detailing each part of the structure. The defects stated are lack of fixity, eccentricity and inadequate rigidity.

Mattavāriṇi:

Two spaces (8H ×8 H) on either side of the Rangapīṭha are kept apart for sacrifice and these decorated spaces with four columns are meant for the protection of the Nāṭyagṛha. The Mattavāriṇi is one of the areas where commentaries present different interpretations and the term is seen in other ancient texts too (Sharma, 2012). The height for the Mattavāriṇi is 1.5 H. While reading in conjunction with the suggestion in Chapter Regarding the presence of deity of lightening in the Mattavāriṇi i, it forces us to believe that Mattavāriṇi is meant for the lightening protection also as metals are placed below these columns.

Rangamaṇḍapa:

The stage structure with a floor height of 1.5 H is recommended. The basement filling of the stage should be with selected earth and that should be well consolidated. Stout work men are recommended and careful construction is to be ensured. It is stated that the surface of the stage shall be of prefect level. A convexity or concavity in the stage is not only an inconvenience to the performer on the stage but also can cause acoustic problems arising from sound concentration. The surface shall also be decorated with gems and jewels.

An additional roof with wooden construction -Ṣatdāru- is required for the Stage structure. This is common in the Koothamblalam in Kerala temples also. The columns and the roof elements shall also be well decorated with carvings.

Walls:

sudhākarma bahistasya vidhātavyaṃ prayatnataḥ |
bhittiṣvatha viliptāsu parimṛṣṭāsu sarvataḥ||
samāsu jātaśobhāsu citrakarma prayojayet |
citrakarmāṇi cālekhyāḥ puruṣāḥ strījanāstathā || NS:2:71

Literal translation: *After wall construction the walls shall be plastered. Then the walls shall be again painted with lime. After ensuring the smoothness, level and brightness of the mural painting can start.*

All walls shall be well plastered with lime mortar and shall be decorated with mural paintings. Here it is pertinent to cite that the Vāstu text *Śilparatna* has an exclusive chapter on mural paintings explaining surface preparation, colour mixing, brush making, painting principles etc. There are also exclusive texts on mural paintings. Kerala is rich in mural paintings and differ styles do exist in this. The important temples and palaces where old mural paintings exist is are many and its theme and detailing are noteworthy (Shasibhushan, 2004).

Special requirements:

stambhaṃ vā nāgadantaṃ vā vātāyanamathāpi vā|
koṇaṃ vā sapratidvāraṃ dvāraviddhaṃ na kārayet | NS: 2:68

Literal translation: *The columns, cantilevers, widows, corners, opposite doors etc. shall not be placed one against other.*

Certain special requirements which differentiate the theatre from the residential construction are also stated clearly. These requirements are essentially from the acoustic point of view in order to increase the quality of sound in the theatre. Construction of columns, brackets & cantilevers, doors, windows and corners coming in a line are to be avoided to reduce chances of echo formation.

kāryaḥ śailaguhākāro dvibhūmirnāṭaīmaṇḍapaḥ ||
mandavātāyanopeto nirvāto dhīra śabdavān|
tasmānnivātaḥ kartavyaḥ kartṛbhirnāṭaīmaṇḍapaḥ || NS 2:69

Literal translation: *The nāṭyamaṇḍapa shall be like a rock cave with a mezzanine floor. Similarly all windows shall be small and wind should not enter freely in to the Nāṭyamaṇḍapa.*

It states that provision of a additional mezzanine roof and making the windows smaller will ensure required reverberation and to avoid external blowing wind effects. Blowing wind can affect the quality of music due to Doppler Effect.

Construction of Square Theatre:

vikṛṣṭe tānyaśeṣāṇi caturaśreƒpi kārayet| NS:2:76

Literal translation: *The construction of square theatures shall be done similar to rectangular.*

It is generally stated that all the construction techniques and rituals recommended for the rectangular theatre shall be applied to the square theatre also.

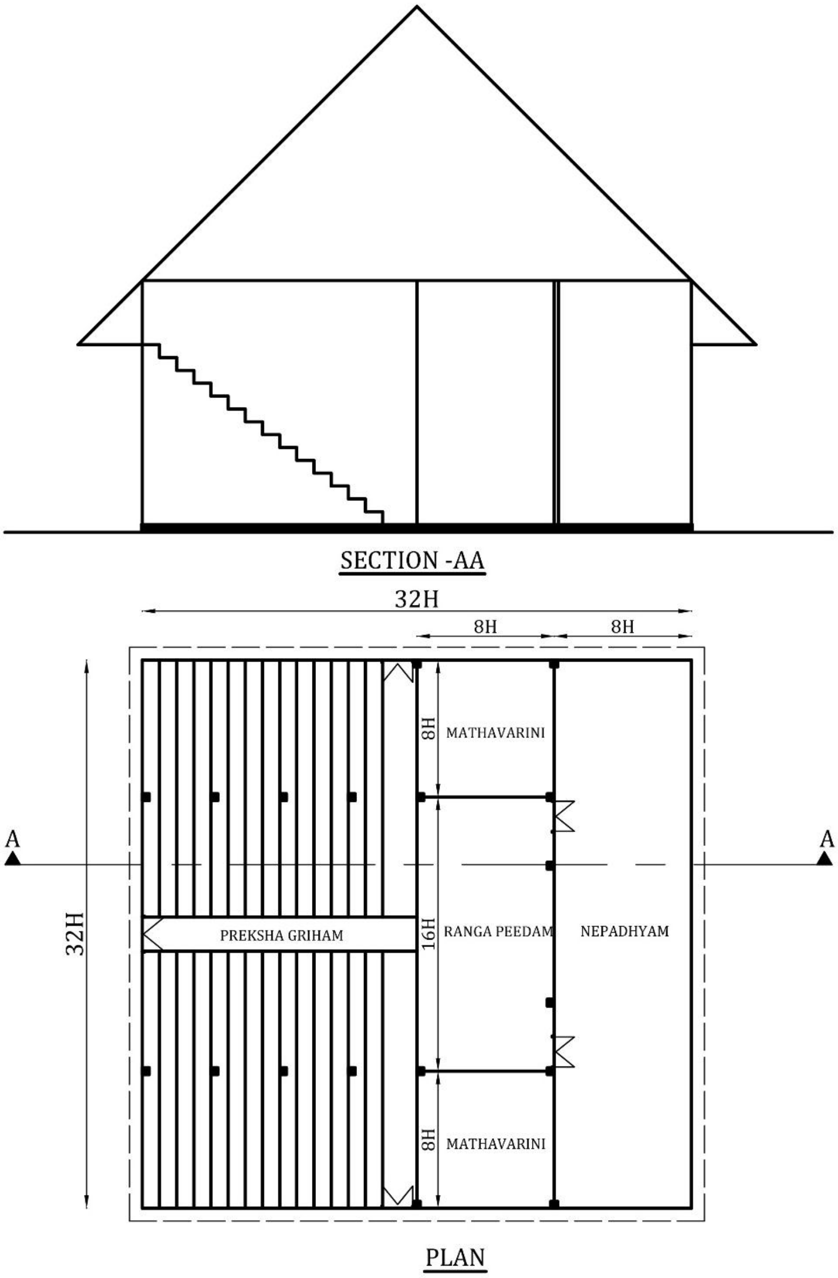


Fig. 6.3 Square Nāṭyagṛha

General arrangement:

As stated earlier the 32 H $\times$32 H building is suggested for the square Theatre. 16 H $\times$ 32 H is for the auditorium, 8H $\times$ 32 H for the Stage and Mattavāriṇi and 8 H $\times$ 32 H for the green room are the divisions. It specifies how to set out walls and build the external walls.

> caturaśraṃ samaṃ kṛtvā sūtreṇa pravibhajya ca|
>
> bāhrataḥ sarvataḥ kāryā bhittiḥ śliṣṭakā dṛḍhā || NS:2:27

Literal translation*: The true squares shall be set out using thread and then walls shall be constructed with good quality bricks strongly.*

The setting out of corner walls with thread in right angles using the right-angle triangle triplet (3.4.5) is given in *Āpastambasūlbasūtra* (c.1000BCE) Peripheral walls of the theatre are load bearing construction with good quality bricks.

Internal columns:

> daśa prayoktṛbhiḥ stambhāḥ śaktāḥ maṇḍapadhāraṇe || NS :2:78

Literal translation: *For carrying the load of mandapa ten strong columns shall be erected.*

Ten columns are recommended in the auditorium portion. Six strong columns on either side of the stage portion are also suggested.

Gallery:

> stambhānāṃ bāhrataścāpi sopānākṛti pī̄ṭhakam ||
>
> iṣṭakādārubhiḥ kāryaṃ prekṣakāṇāṃ niveśanam| NS:2:79

Literal translation*: Between the columns gallery shall be erected in the shape of steps made of bricks or wood.*

In the square Theatre, for seating the audience, a gallery (stepped seating arrangement) is suggested. This gallery shall be provided in between the ten columns mentioned above and on either side of the row of columns. The width of each step shall be 1 H and rise shall be 0.5 H. The steps are to be constructed either with bricks or wood.

Rangapīṭha:

A square Rangapīṭha of 8H × 8 H and no additional basement height is required for the stage (Rangapīṭha). The stage in floor level is recommended since the seating arrangement is stepped.

Mattavāriṇi:

The spaces as in the case of Rectangular Theatre on either side having 8H × 8H size and four columns for each Mattavāriṇi are required.

Triangular Theatre:

> tryaśraṃ trikoṇaṃ kartavyaṃ nāṭyaveśmaprayoktṛbhiḥ |
> madhye trikoṇamevāsya raṅgapīṭhaṃ tu kārayet || NS:2:90
> dvāraṃ tenaiva koṃṇena kartavyaṃ tasya veśmanaḥ |
> dvitīyaṃ caiva kartavyaṃ raṅgapīṭhasya pṛṣṭhataḥ || NS:2:91

Literal translation*: The triangular Theature shall be with three vertices and the stage portion also in the triangular shape. The entry shall be through one corner and another door behind the stage also.*

For the triangular theatre, as stated earlier the dimensions are not clearly stated. Similar to the square theatre base width equal to 32 H and altitude 64H based on Vision triangle a geometry is suggested.

The Rangapīṭha recommended is also triangular. Two entries, one through one of the corner (Vertex of the triangle) and one from the rear side are recommended. For other details it is stated that the rules for the other shapes hold good for this type also.

Koothamblalam in Kerala temples are modified form of Nāṭyagṛha. They do not strictly follow the plan set out by *Nāṭyaśāstra*. The major difference noticed is that Nepathya (Green Room) is smaller when compared to the one prescribed in *Nāṭyaśāstra* (¼th of length of the Nāṭyagṛha). See sketch of Koothamblalam in Guruvayoor, Moozhikkulam and Irinjalakkuda.

The Nāṭyagṛha will be usually facing east. There will be flag posts (jarjjara). The flag post is called Indradhvaja and in temples etc. it serves as a lightening protector also due to its mode of construction.

In all temples there will be Dvajastabha for hoisting the flag during the festival. These Dvajastabha (flag post) will be the highest structure in front of any temple not farther than its height from the sanctum sanctorum. The verse details its construction. Since posts have annular copperplates as outer shell of the wooden post properly grounded 2 m below helps to dissipate energy during lightening. Moreover since the area covered is a circle with its own height, the whole building will be properly covered. In Bijil Mahadeva Temple in Kulu, it is a well-known fact that the post protects the temple as it is located up hills in a lightening prone area (Bijil in Hindi language means lightening).

In Nāṭyagṛha also, Bharata has recommended Jarjjara or flag posts. Moreover below Mattavāriṇi columns also, metal pieces are kept and it is mentioned that these are for the vidyut or lightening.

6.3 CONCLUSION

On studying Nāṭyagṛha specification, it could be seen that in the design of special structures like Theatre, ancient Indians have proved their mettle in understanding vision triangle and acoustics of auditoriums. The rationale behind the sizing of the theatre has been derived in the present study. Thereby the solution to the unresolved issues regarding the triangular Theatre is arrived in the present study.

CHAPTER 7

SOIL MECHANICS AND FOUNDATION IN VĀSTU

7.1 INTRODUCTION

The sixty-six meter (216 ft.) high Rajagopuram, royal entrance in the East of Thiruvannamali temple built around 900 CE situated in the state of Tamilnadu is standing without any settlement or distress for the past thousand years. So are many other Gopuras (Towers) and Vimanas (main structure) including the highest one (63.4 m) in the Brihadeswara Temple built in 1010 CE with an eighty (80) tones of capping stone at the top. They stand testimony to the traditional engineering wisdom of our country. There are many time-tested structures throughout India surviving numerous floods, hurricanes and earthquakes; none of them had failed on its own, but some of them sadly disappeared or shattered by human intervention (Nehru.1934).

One interesting fact is that many of the sites are not in hilly areas but on river banks or on the shores of backwaters or on the seaside. Again, Tanjore in the banks of Cauvery, would be the best example to cite. In Kerala also, it could be seen that the major ancient temples in Guruvayoor, Irinjalikuda (Koodalmanikkam), Kodungaloor, Peruvaram (Parur), Thekkanchittoor, Cheraneloor, Ernakulam, Tripunithura (Poornathrayeesa), Udyamperoor, Udyanapuram, Vaikom, Thirumanivenkatapuram, Thuravoor, Sherthalai, Kayamkulam, Karunagappilly, Kollam (Anadavalliswaram), Chirayankizh, Varkala, Kazhakkottam etc. are along the coastal line. These were constructed in sandy soil or sandy-clay type soil where underlying intermittent clay layers are existing. Foundation and basement of none of them till date has shown any major subsidence though in some cases the superstructure especially roof structure has been repaired or replaced. On examination of basement and main structures the above temples, all of them are surviving for centuries without any major structural problem though founded in the coastal belt of Kerala. From the performance of the ancient structures, it could be concluded that the traditional approach in the provision of foundation was suffice to prevent settlement and ensure its performance. An analysis and study on the Vāstu prescriptions are made in the light of modern geotechnical engineering in this respect.

7.2 FOUNDATION IN VĀSTU

As mentioned in the earlier chapter on site selection, the traditional buildings were constructed only after a very careful site selection. Rigorous procedures were followed for selecting a suitable site. In a period when abundant land was available and affordable, a careful selection process was very much possible and practical. This procedure resulted in suitable location where soil has all the desirable qualities including good bearing capacity with practically no chance of any settlement. The designs also were done taking care of many aspects giving very little chance for differential settlement as the geometry adopted were regular, symmetric and low aspect ratio. Similar to modern 'soil testing', the very same terminology, Bhūparīkṣā is used in Vāstu texts too.

When structures are to be founded in sandy layers where underlying clayey layers are present, careful analysis is required. Assuming that for residences in olden days, there were only maximum two floors and that too load bearing construction and hence spans were moderate, the bearing pressure (p) works out be in the range of 40-50 kN/m^2 and assuming bulk density of soil, γ_d as 18kN/m^3, the significant depth, $h = \frac{p}{\gamma_d} = \frac{40}{18} = 2.2m$. Usually depth of exploration is required up to the significant depth. Also, this is assumed 1.5 to 2 times the loaded area. Here the width can be assumed as 1*m* and hence the significant depth can be assumed to be 2.2*m*.

Going through the Vāstu texts, the depth of excavation is recommended as follows:

> khātvākṣiti tā puruṣapramāṇa jalāntamaśmāvadhi vā sulagne|
> pādonamāpūryaviśuddhavedyā rātrī̄ yajeddiśyathavāstumaiśyām || SR 10:4

Literal translation: *Excavate up to depth of Puruṣapramāṇa. Or up to depth of ground water table or up to the rock level, then backfill it with clean earth (specification given later), up to a depth three-fourth of the excavation*.

Here the texts say to excavate up to Puruṣapramāṇa. More precisely defined as puruṣāñjalipramāṇa which refers to the total height of a person whose both hands are stretched up and folded together. For a standard person with 6ft height it will be 2.25 *m*. Otherwise excavate up to ground water level, *Śilpiratna* recommends that desirable ground water table shall be at the same depth specified above, i.e. puruṣāñjalipramāṇa. Here it could be seen that exploration is done roughly in the range of significant depth. The critical depth criteria are also met. For important structures, excavation up to the rock was the practice. Initially filling will be done for ¾ the depth of excavation initially. The 'Śilānyāsam' (*ceremonial foundation stone laying*) is done at that level only. Then again filling will be done for the balance depth at which foundation bed is provided below the basement. For the temples and other important structures, the bedding will have rock cut slabs and for residences etc., it will be laterite or brick. The specification for filling is given in detail in Śilpiratna under the subhead 'mṛtpūraṇam' (backfilling).

saśarkarairvālukaiścamṛdbhiścadṛṣadādibhi |
dṛḍha prapūrayecchuddhairjalairāplutyamudgara||
musalairbṛhacchiraskestunihatya dṛḍhatā nayet|
gajasañcāraṇatatrabahuśakārayetpunaḥ || SR10:15/16

Literal translation: *The backfilling shall be done with mixture of clean boulders (stones), coarse sand, fine sand and soil and compact it by intermittent watering (clean water) and ramming with wooden rammer and wooden pestle. Finally, it must be consolidated with elephants by walking over the fill several times.*

Mayamata also recommends the same:

khananaṃkriyamāṇasyavastunaścabalaṃyathā |
rūḍhotpalakṛśervādisaṃyuktaṃtanuvālukam || MM:14:3
anūpamitivikhyātaṃkhātvaivā jaladarśanāt |
iṣṭakopalamṛdbhiścavālukairapicikkaṇaiḥ|| MM:14:4
śarkarābhiḥkramācchvabhraṃniśchidraṃpūrayetsthiram|
ghanīkṛtyebhapādaiścakāṣṭhakhaṇḍairbṛhattaraiḥ ||MM14:5

Literal translation: *Excavate up to a level where water is seen. Then fill it with brick bats, soil, Coarse sand, builders in layers without voids by filling continuously and compacted by elephants and wooden rammers several times.*

Here it is noteworthy that for backfilling, Vāstu has also specified well graded mixture of gravel, sand and soil. The relevance and importance of the need for a well graded engineered backfill material for ensuring proper compaction was seen clearly identified in Vāstu. Clean materials with debris are also specified in particular, so also the quality of water. Need for intermittent watering and proper ramming with types of rammers specified, one with a flat (Rammer) and other round headed (pestle). Finally, the entire area was compacted by making elephants to walk several times. In this context, *Nāṭyaśāstra* interestingly says that the workmen deployed for the backfilling shall be 'heavy built' in particular. NS 2:63.

After compaction, *Mayamata* recommends to check the sufficiency of compaction by following test.

> tatkhātesalilenaivapūriteƒkṣatayā śubhā|
> samatvaṃsalilenaivasādhayitvā vicakṣaṇaḥ || MM14:6

Literal translation: *When water is filled over the compacted surface, if water does not disappear fast, it is a good indication, the level also could also be assessed by the experts.*

After compaction, *Mayamata* recommends to make water to stand on it. If water percolates slowly, it means compaction is sufficient. By keeping water, the levelling could also be checked.

While fixing the finished ground level, there was a system of raising the proposed ground level. This was very clearly indicated in several texts. The verse from

Manuṣyālaya Candrikā is quoted below. Raising the ground level was also done by well graded soil as specified above. This is done in the range of 24, 36 or 48 *cm* according the site condition. *Mayamata* recommends 72 *cm*. This will ensure proper drainage from the central courtyard and raised platform will present the ingress of dampness. In those days transportation of earth for filling was a difficult task and much lead and lift posed problems. For large temple complexes and palaces, initially a large pond will be constructed and the entire excavated earth will be used for the ground improvement and land development. Thus, construction of ponds was sequenced first.

> kuryādgṛhāyakṛtavāstupadaṃsamastaṃ
> mātaṅgabhāskaranṛpāṅgulamātratuṅgam||
> bāhrāntarāṅgaṇagatāngamanāyamadhya-
> nimnatvadoṣavirahāyacamṛcchilādyaiḥ || MC 5:1

Literal Translation: *The set-aside lot for house (Vāstupadam) shall be raised by mātaṅga(8),Bhāskara(12)or Nṛpa(16) Aṅgulas. This is to ensure flow from central courtyard to outer and to rectify the defect (if any) of the central depression. The filling shall be done by soil etc.*

Here an interesting feature of scientific literature in Sanskrit may also be noticed. While versification, since the rules of meters (Chandas /Vṛtta) shall be mandatorily followed, embedding numbers when required becomes difficult and may affect the literary beauty of the verse. Hence in scientific literature, numbers are embedded using two techniques, Bhūtasaṅkhyā system and Kaṭapayādi system. Usually in formula, Bhūtasaṅkhyā is used and in giving mathematical constants Katapayadi is used. Here bhūtasaṅkhyā is used to denote 6, 8 and12 as *aṣṭa* (8) *diggajas, dvādaśa* (12) *ādityas and ṣoḍaśa* (16) *nṛpas*. In the other system, Sanskrit consonants are numbered starting with ka as one (1). In most of the Vāstu texts, these types of expressions could be found in plenty. In *Manuṣyālayacandrikā*, many numerals are depicted in Bhūtasaṅkhyā system. One of the first mention of zero is found in Cambodia in an inscription in a Temple in Śaka year which is in this Bhūtasaṅkhyā system. *'Mūrtivyomaaṣṭabhūtaśaka'* meaning 'mūrti (1), vyoma (1) and aṣṭa (8) expressed in Bhūtasaṅkhyā system denoting the Śaka year. (The numbers when written in Bhūtasaṅkhyā will be in the reversed order, hence the year 811 Śaka (AD 889) is inscribed. Cambodia houses many temples as most of the south-east Asian countries were under the influence of Indian culture and Sanskrit learning. The Angkor Wat in Cambodia, one of the largest religious monuments in the world built by the Khmer King Suryaverman–II, as a Vishnu Temple in 12th Cent is also constructed according to Vāstu principles and rules.

7.3 SOIL INVESTIGATION

All Vāstu texts have a chapter on 'Bhūparīkṣā' meaning testing site (soil). In site selection processes, some engineering properties of soil were also analyzed and investigated though in a rudimentary form which could be seen as anticipations of several modern theories and methods in the Geotechnical engineering procedures and investigation.

With reference to IS 1892-1979: Indian Standard code of Practice for subsurface Investigation for Foundation, the parallels in the traditional approach in site reconnaissance and site investigation and current practices could be seen easily.

Clause 2.1 says *‘the advantage should be taken of existing local knowledge’*, *Manuṣyālaya Candrikā* (c.1550) says, the prime Engineering Consultant (Ācārya) shall be ‘*taddeśasambhinnānām’* meaning knowing the data and details of the locality.

Clause 2.2.1.3 ‘*The type of flora affords at times some indication of the nature of the soil. The extent of swamp and superficial deposits and peats will usually be obvious’*.

Referring to *Manuṣyālaya Candrikā* (c.1550), it speaks that good site shall have flowering and fruit bearing plants and especially plants and trees of *Ficus* family. Here MC is more specific about the species and hence there is a scope for further investigation in regard. Code also specifies to assess ground water table, so also the Vāstu texts and suggests to have water table at a depth of preferably at 2.25 *m* depth (Purushanjali as mentioned earlier).

Clause 2.2.2 suggests to enquire about the earlier uses of site. For this, Vāstu texts suggests to plough the plot and examine soil. Verse in TS states that while ploughing if the soil has *charcoal, bones, nails, waste, worms, ant-hills, with central depression, with inner caves and fissures*’, that must be avoided . This clearly indicates the early use of land as waste disposal, graveyard, and reclaimed area with undesirable materials.

The geophysical test as per clause 2.2.3.2 Seismic method.

"The seismic method makes use of the variation of elastic properties of the strata which affect the velocity of shock waves traveling through them, thus providing a usable tool for dynamic elastic moduli determinations in addition to the mapping of the subsurface horizons. The required shock waves can be generated by hammer blows on the' ground or by detonating a small charge of explosives. This method is quite useful in delineating the bedrock configuration and the geological structures in the subsurface".

A crude form of this test is indicated in Vāstu tests also. Generate shock waves on ground by tampering and then analyse the nature of ground. If 'Dhīrarava' (low frequency sound) is produced it indicates a good substrata. This might have been done in early days by practice by observing the nature of the sound resulting when tapping. Now this could be regarded as the forerunner of "Acoustic Characterization of Soils" under seismic method of testing.

Under the clause 2.3, sub clause 2.3.1, the Number and Disposition of Trial Pits and Borings are depicted. *'For a compact building site covering an area of about 0.4-hectare, one bore hole or trial pit in each corner and one in the centre should be adequate. For smaller and less important buildings even one bore hole or trial pit in the centre will suffice'*

Vāstu also suggests to have the test pit at centre of the plot.

Referring to Verse 92 in Chapter 53 *Bṛhatsaṁhitā* (585CE) gṛhamadhyehastamidaṃkhātvā paripūritaṃpunassabhram |

yadyunamamniṣṭaṃtat same samedhanyamadhikaṃ tat || BS 53:92

Literal translation: *In middle of the proposed house, dig a pit of one Hasta and then fill it with the excavated earth. If soil is in excess, the land Uttama (excellent). If it just fills it is Madhyama (acceptable).*

7.3.1 Site Investigation Procedure

As per the IS 2131-1981, clause3.3.3: "The split spoon sampler resting on the bottom of borehole should be allowed to sink under its own weight; then the split spoon sampler shall be seated 15 *cm* with the blows of the hammer falling through 75 *cm*. Thereafter, the split spoon sampler shall be further driven by 30 *cm* or 50 blows (except that driving shall cease before the split spoon sampler is full). The number of blows required to effect each 15 *cm* of penetration shall be recorded. The first 15 *cm* of drive may be considered to be seating drive. The total blows required for the second and third 15 *cm* of penetration shall be termed the penetration-resistance N; if the split spoon sampler is driven less than 45 *cm* (total), then the penetration resistance shall be for the last 30 cm of penetration (if less than 30 *cm* is penetrated, the logs should state the number of blows and the depth penetrated)."

In the Vāstu text, the topic dealing with '*śaṅkutāḍanam* has some similarities mainly qualitatively with standard penetration test (Terzhaghi,1943). This is essentially driving pegs at four corners and at middle points and at centre of the site. *Tantrasamuccaya* states the following and the same is quoted in *Śilpiratna* also

punnāgaikatarūdbhavānkaramitāntatpādanāhān dṛḍhān
śaṅkūnprāgvidhināthamantramahitānmadhyādiśarvāntimam ||
mātvā kalpitasālasīmniparita śaṅkudvisaveṣṭita
mantrī sapravisāryasūtramapigṛhṇātukṣitisarvataḥ || TS1:20 (SR 4:4)

Literal translation: For all temples irrespective of deities, Gnomons shall be made of Punnaga wood, one Hasta long (720mm) and six Angula (180 mm) circumference, after reciting Astra mantra, facing East , in the centre one Gnomon and then from N-E corner onwards in eight directions (N-E, E, S-E, S, S-W, W, N-W and N) position all gnomons and tie it with Darbha grass.

From the above description, it can be seen that the Śaṅku (gnomon) is positioned with care ritualistically. It is also made with care in standard dimension with same quality using same timber. As per IS 9640:1980, the split spoon sampler is 500 *mm* long and 50 *mm* dia. Here Vāstu gnomon is 720 *mm* long and 57 *mm* dia. Sampler is metallic and hollow, here it is wooden and solid. In modern practice, the blows for standard penetration is taken and correlated to other soil parameters but in olden days it was only qualitatively assessed as given below.

tattatsīmāsutacchaṅkūnvinyasyaprathama guru |
tāḍayellohakūṭenamudgareṇāthavā samam || SR 4:5
nāśmanā(vā) nakāṣṭhena tāḍayeddoṣakṛdyata |
tataḥ śilpī yatheṣṭatu śaṅkūn kūṭena tāḍayet || SR 4:6

Literal translation: *After positioning the gnomon in all directions, it shall be driven in order with Iron hammer. For driving, wooden pieces or stones shall not be used.*

From the above it could be presumed that as the length and diameter of Gnomon is specified there could be a standard hammer also in use. The number of blows as per Vāstu is eight (8), '*tāḍayedaṣṭabhi: kramāt'* (MM 6:18).

> sahasā praviśecchaṅkurnaviśedvātravighnakṛt |
> śanaivrajannṛju śaṅkukarmasiddhi tadā vadet || (SR: 4:7)

Literal Translation: *If it penetrates very fast, the land is unsuitable to live. This will create many problems. On the contrary if it goes down slowly that land has constructability.*

Clause #3.3.3.1. The entire sampler may sometimes sink under its own weight when very soft sub-soil stratum is encountered. Under such conditions, it may not be necessary to give any blow to the split spoon sampler and SPT value should be indicated as zero.

The above clause and Vāstu conclusion in this regard are obviously the same.

Ground Water Table:

Area where perennial ground water is available is considered as best and that too at a depth of 2.25 m.

> yā sā snigdhā mahī khyātā tanuvālukasayutā|
> puruṣāñjalimātretudṛṣṭātoyasamanvitā || SR 10:2

Literal Translation: *In Sngidha type land, there will be slow flowing in of water and at the depth of Purushanjali (2.25m) water will be there.*

Properties of soil:

Permeability of soil and density of soil are two important soil properties that are considered in modern geotechnical engineering. In *Bṛhatsaṃhitā* (585CE) also, these properties are discussed in detailed manner.

> śvabhrāvambupūrṇam padaśatatamitvāgatasya yadi nūnam/
>
> taddhanyaṃ yacca bhavetpalāni pāṃsvāḍhakaṃ catuṣṣaṣṭi// BS: 53:93

Literal translation: *In the pit fill water and walk 100 steps away from pit amd come back and watch. If level has only reduced one Angula, the soil is good. Similary the weight of four. Aḍhyakam of soil shall be sixty-four Palas*

Permeability Test in Vāstu:

Make a pit 72 *cm* × 72 *cm* ×72 *cm* and fill it with water and then walk 100 steps and return. If water level remains almost same, it indicates a good soil and if water has gone down by 1 Yava ($1/8^{th}$ of an Aṅgula), it is acceptable soil.

For the analysis of permeability coefficient, there is no direct formulae available. The currently used open pit method makes only a shallow depth and flow through the sides are ignored. Here since all dimension's length, width and depth are same such a treatment will be erroneous. Hence a formula is derived from first principles using Darcy's theory.

Since the pit size is H $cm \times$ H $cm \times$ H cm, consider an analogy with the constant head permeability test with a head of H cm. Let us assume a thickness 'x' at bottom act as drainage layer (Fig. 7.1).

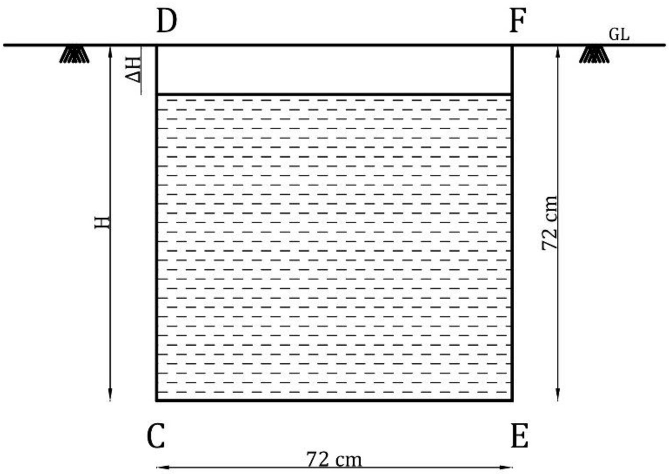


Fig. 7.1 Permeability test

Dip in level = ΔH

This formula is derived from first principles using Darcy's theory.

Since the pit size is H cm x H cm x H cm, consider an analogy with the constant head permeability test with a head of H cm.

Let us assume a thickness '2x' at bottom act as drainage layer.

Dip in water level after time't' sec = ΔH

Then total **quantity of water percolated** $Q = H^2 \Delta H$ .... (1)

The velocity at any depth y is proportional to $\sqrt{y}$

Let volume draining in to soil through 4 sides of the pit is Q_1

Then $$Q_1 = 4.H\int_0^h C\sqrt{y}dy = \frac{8}{3}CH^{5/2} \quad \text{.......................................} (2)$$

Where C coefficient of percolation.

Let water draining through the bottom be Q_2

$$Q_2 = CH^2\sqrt{H} = CH^{\frac{5}{2}} \text{...}(3)$$

From Eq.2 and Eq.3 $$Q = Q_1 + Q_2 = \frac{11}{3}CH^{5/2} \quad \text{..} (4)$$

From Eq.1 and Eq.4 $$H^2\Delta H = \frac{11}{3}CH^{5/2} \quad \text{..} (5)$$

$$\therefore C = \frac{3\Delta H}{11.\sqrt{H}} \quad \text{..} (6)$$

$\therefore$ Quantity drained through bottom after substituting the value of C from Eq.6

$$Q_2 = H^{2.}.C\sqrt{H} = CH^{5/2} = \left(\frac{3H^2\Delta H}{11}\right) \quad \text{........................} (7)$$

Let $2x$ be the thickness that will get soaked during the test and assuming 50 % voids

$$\therefore H^2 \times (0.5) \times 2x = CH^2\sqrt{H}$$

$$\therefore 2x = C\sqrt{H} = \frac{6\Delta H}{11} \quad \text{...} (8)$$

$$\therefore x = \frac{3\Delta H}{11} \quad \text{...} (9)$$

Average Thickness of layer getting soaked during the experiment will be x

$$\therefore x = \frac{3\Delta H}{11}$$

Using the equation, $k = \frac{qL}{h}\frac{1}{A}$ .... (10)

Where L thickness of sample, h is the head, A area and q quantity of water flown in one sec and k coefficient of permeability in cm/sec.

Now consider the bottom of the pit:

The thickness of layer through which water penetrates is 2x

Area = H^2

Head at bottom = $\bar{h} = H$

Now $L = x = \frac{3\Delta H}{11}$ (average thickness)

Let $q_2 = \frac{Q_2}{t}$

When we consider drainage through bottom only h=H and using Eq.10

$$k = \frac{q_2 L}{h} \cdot \frac{1}{A} = \frac{1}{t}\left(\frac{3}{11}\Delta H . H^2\right) \cdot \frac{3\Delta H}{11H} \cdot \frac{1}{H^2} \cdot = \frac{1}{H}\left(\frac{3\Delta H}{11}\right)^2 \frac{1}{t} = 0.074\left(\frac{\Delta H}{.H}\right)^2 \frac{H}{t}$$

From the above Coefficient of permeability k will be as follows

$$k = 0.074\left(\frac{\Delta H}{.H}\right)^2 \frac{H}{t} \quad \text{..} (11)$$

Limit of permeability coefficient, k= 1.45 x10^{-4} *cm/sec.*

Usually for 100 steps 1 minute is considered as a standard.

Hence, Time for 200 steps= 120 *sec*:

For different soil types as per grain size, the orders of magnitude for permeability are as follows: According to modern classification of soils, the permeability of soil type silty sand is the range of 10^{-3} to 10^{-4}*cm/sec.*

Bulk density of soil:

Next line in the above referred verse from *Bṛhatsaṁhitā* discusses about the bulk density of soil. Recommended value is four Aḍhyakam (Volumetric measure) must be weighing approximately 64 Palm. Aḍhyakam is roughly 1330 *cc* in modern units and 1 palam is approximately 36 *grams.*

Hence Bulk density $= \gamma_d = 1.728 \quad g/cc$

Compaction test:

In present day engineering practice to control settlement, two important aspects of existing soil structure are primarily considered. Any soil strata are constituted by soil, air and water. In simple terms, the expulsion of air is called 'compaction' and expulsion of water is called consolidation. For a good bearing strata, Engineers look for a well compacted and consolidated soil. In such a strata, the grains of soil will be well packed and on loading there will little room for rearrangement of grains within preventing excessive settlement. Thus, a good soil will be densely packed, Vāstu tradition had also recognized this aspect and suggested a simple test, to verify its degree of compaction. This desirable property is called 'bahupāṃsu' in Vāstu terminology. While condensing all the desirable attributes of a site in single verse, TS has also included this. This is stipulated in one way or other in all ancient texts. For instance, *Matsyapurāṇa* (300BCE) Chapter 252 – Verse 17, states that if the excavated earth is more than the quantity sufficient for back filling, the site is very good and it is just suffice. It is good and other wise unsuitable.

The term 'bahupāṃsu' is detailed in many texts like *Bṛhatsaṁhitā* (585CE) in detailed manner. Referring to *Bṛhatsaṁhitā*,

> gṛhamadhyehastamidaṃkhātvā paripūritaṃpunassabhram |
> yadyunamamniṣṭaṃtat same samaṃ dhanyamadhikaṃ tat || (BS:53:92)

Literal translation: *In middle of the proposed house, dig a pit of one Hasta and then fill it with the excavated earth. If soil is in excess, the land Uttama (excellent). If it just fills it is Madhyama (acceptable).*

Take a pit at the centre of the proposed building having a size 1H(72*cm*), 1 H(72 *cm*)×1H (72*cm*) in size. Refill the pit with excavated earth. If soil is insufficient for back filling, the area is unsuitable (bad) for any construction. If soil is just sufficed it is acceptable (good) and if spoil is in excess it is highly recommended (best). Comparing with proctor compaction test, if we can measure the percentage of excess earth, it could be an indication of 'degree of compaction' the layers have undergone. For good soil about 25% of bulkage is usually recommended (CPWD measurement specification). In this context, an arbitration case regarding Earthwork contract related to a major petrochemical Project executed in Cochin regarding uncommon shrinkage of excavated earth and consequent reduction in quantity compared to the theoretical earthwork quantity due to the special nature of the soil is worth mentioning.

This Vāstu method could be developed as a method ascertaining in-situ percentage of compaction, by measuring the in-situ bulk density, moisture content and the percentage excess the degree of compact of the existing soil can be ascertained.

Vortex Test

Take a pit at the centre of the proposed building 1H (72*cm*), 1 H (72 *cm*) × 1H (72*cm*) in size. Fill it with water. Watch the draining of the water by putting a flower as a float. If it drains fast vortex will be formed and definitely it will be in the anticlockwise direction. Due to Coriolis Effect (AndersS, 2005) in Northern hemisphere vortex formation will be in the anti-clock wise direction. If it drains forming an anti-clockwise vortex, it indicates that there are fissures in substrata and hence unsuitable. The relevant verse in MC is given below.

bhūgartejalapūrite*f*travidhivaddroṇādipuṣpaṃkṣipet

prādakṣiṇyagatiḥ śubhaṃsumanasāṃyadyanyathā ninditam | (MC 1:33)

Literal Translation: *In the pit according to the rule, put a flower (droṇa flower etc.) If flower circumnutates clock wisely, it is good and if moves in anticlockwise direction it is not good.*

The validity of the test can be demonstrated with a simple pan with bottom hole and placing a flower in the filled water by closing the hole with thumb.

Classification of soil:

Classification of soil and study of its engineering properties is the main portfolio in modern soil mechanics. In the same lines Vāstu has also attempted to classify soils.

The soil is classified in to *paṅka (Clay), snigdha (Sandy-clay) and asnigdha or Śarkari (sandy)..*. The soil type snigdha (soil with slight oily feeling when rubbed with fingers –sandy-clay) is considered best for residential areas. In *Mayamata* it is clearly said that too much sandy soil and clayey soil are undesirable but snigdha or sandy-clay is recommended by Vāstu.

paṅkasaṅkarakūpaiścadārubhirloṣṭakairapi |

śarkarābhirayuktā yā bhasmādyaistutuṣairapi || (MM 3:9)

Literal Translation: *Clayey land with discarded wells and soil contaminated with wooden logs, charcoal, husk etc. and devoid of sand shall be unsuitable.*

Further clay is classified in to four *Cikkaṇa, Paṇḍāra, saloṇa and tāmraphulla*, here *tāmraphulla* is suitable for brick making. *Mayamata* has classified two types land for use.

Foundation in Vāstu:

According to *Śilpiratna*, the foundation is defined as follows.

> prāsadastu nijairaṅgairadhitiṣṭhati yaṃ sadā/
> dṛḍhaṃ śilādighaṭitaṃ tadadhiṣṭhānasaṃjñitam// SR:17:1

Literal translation: *Prāsāda (Building) with its different parts rests on which part of the same building, that part which is made of strong stone etc. is called Adhishtana (Foundation).*

The structure (prāsādam etc.) with its different parts, rests on which part of the same building which is made of strong stone etc., that part is called Adhiṣṭhāna (Foundation and Basement) is a good definition. Usually for residences, the basement height adopted is 1 H (72cm).

An interesting general observation on traditional buildings is that they are foundation ***less structures*** from a modern perspective. For rehabilitation or reconstruction, when excavated nothing like 'foundation' is seen other than a strong bedding of stones/ laterite forming the base for the basement. On the contrary modern practice and belief is that 'deeper we go, stronger it becomes' and consequently a large quantity of natural resources like rubble are sacrificed underneath.

If it is analyzed in the context of Kerala, mainly three types soil conditions exist in Kerala. In the upper hilly region, strong lateritic soil is available and for load bearing construction there is no need for going very deep and filling the foundation with rubble masonry. In the coastal belt where there is intermittent layers of sandy soil and clays indicating deposit of sand by sea with considerable time-gap in the past geological history. Here when there is a sandy layer at the top, when deeper foundations are made, the stress contours will definitely encroach into the clayey layers resulting in more settlement than its top placement. The other soil condition is clayey where a deep foundation is required or suitable soil improvement is required. Traditional buildings never went too deep in former two cases wisely and for the third case up to the level of hard strata soil was excavated and removed and replaced with well compacted layer soil or soil mixed with stones. Thus, these structures were properly and carefully founded on earth fully understanding the intents and purpose and the structures have survived test of time for centuries standing against many cyclones and earth quakes. Moreover, most of them are still functional and serviceable.

Basement in Vāstu:

Basement height of common residences is one Hasta or 72 *cm*. This was the height previously adopted in Kerala. This had a definite advantage especially in flood prone areas in giving a sufficient warning regarding inundation of houses. The traditional system of raising the site at by 36 *cm* (48 *cm* in some cases as mentioned in earlier paragraph) and then providing a clear basement height of 72 *cm* was very much advantageous in Kerala where rainfall is heavy and most of the residential areas are in the flood plains of rivers. System of 45 *cm* basement was an introduction of British which is now adopted in National Building Code (Clause #12 Part. Buildings). The minimum height of basement usually provided is 48*cm* as per Vāstu rules. However, the basement height is proportionately given based on total height which is aesthetically pleasing.

> nṛṇāṃ dhāmani pādamānamuditaṃ svasvottaropānaho-
> rmadhyaṃ sāṅghrikaratrikonmitamidaṃ tvalpālaye dṛśyate ||
> gehavyāsasamaṃ tadardhasahitaṃ vyāsābdhiṣaṭsaptava-
> svaṅkāśāṃśayutaṃ ca tairvirahitaṃ caivaṃ munīndrā jaguḥ || MC:5:13

Literal Translation: *In residential construction, the height between the Padukam to Uttara is called Pādamāna. In small house, this seen as 3 Hastas and 6 Aṅgulas. Sages have prescribed Pādamāna as equal to width of the house or its one and half times or 5/4,7/6,8/7,9/8,10/9,11/10,3/4, 5/6.6/7,7/8,8/9 or 9/10 (of width).*

Here it says that the Pādamāna, ie height from the shoe of the house to the bottom of the wall plate is minimum 3H6A for small houses. The basement height (adhiṣṭhānamāna) is dependent on the Pādamāna. (SR and MC quotes this from TS). Usually 1/3 to 1/12 of Pādamāna is taken as basement height (MC 5:14).

7.4 BASEMENT IN VĀSTU

The basement traditionally was decorated with a moulding (usually sculptured for temples etc. from rock itself as an integral part) popularly known as ' pañcavarga' which was a unique outstanding feature of our traditional buildings. This is currently provided for Temples where as in previous days it was mandatory. The parts of a pañcavarga basement are 'pādukam, kumudam, jagati, gala, patti' See the sketch below. This not only added to the beauty of the basement but also acted as a reptile trap owing to its unique design (Refer Fig. 7.2).

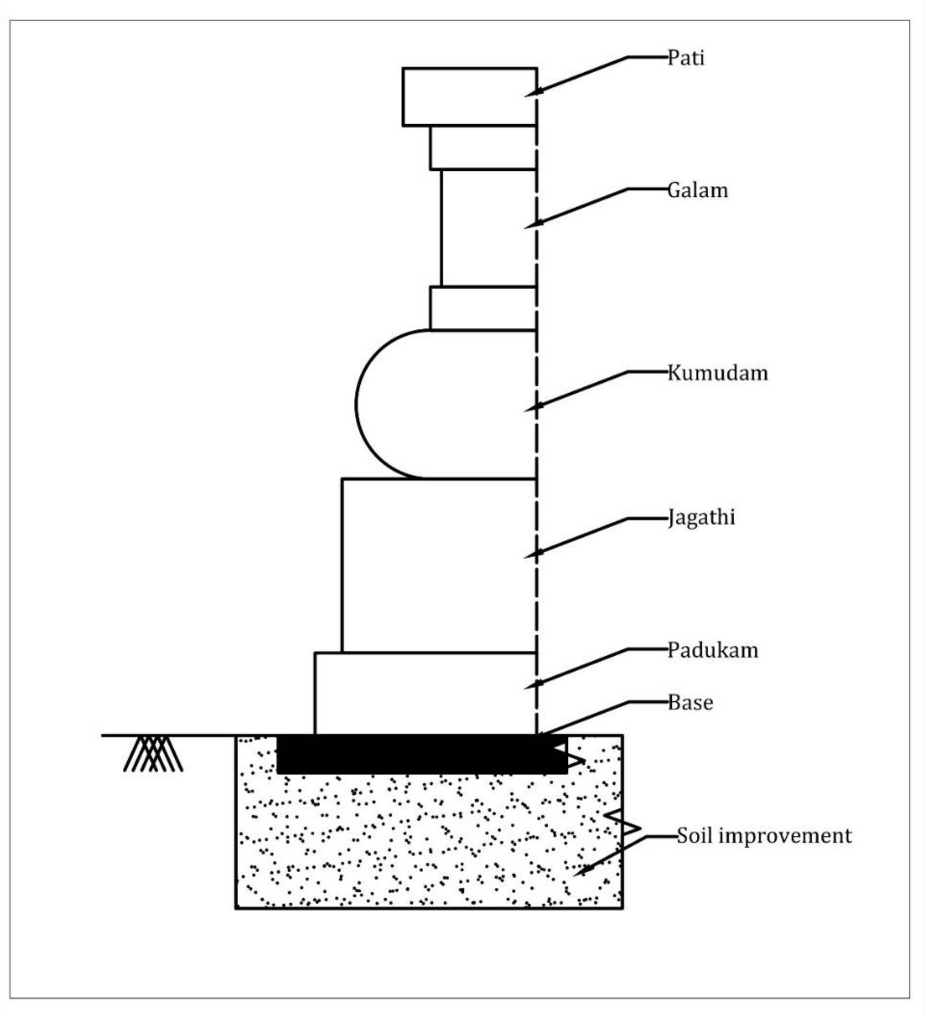


Fig. 7.2 Parts of basement

Apart from Basement, usually an Upapīṭham or substructure for the basement was also constructed. The purpose of which is given in *Mayamata* etc. MC says as follows.

> rakṣāśobhocchrāyārthaṃ sakalanilayamāsūratoƒdhaḥ samantāt |
>
> kuryād ekadvihastapravitatam upapīṭhaṃ gajādyaṅgulāḍhyam || MC:5:2

Literal translation: *Below the Basement of all houses an additional sub-basement shall be made with width one or two Hasta with increments 8 Angula for strength, beauty and height*

For protection, elegance and for achieving height, an additional seating may be provided with a width of 1H- 8A to 2H-16 A.

Usually its height is equal to basement height or 1/6 to 1/10 less of its height. All parts (Pañcavarga) of basement shall be provided in Upapīṭham. This is the system of providing around Verandah which was common in olden days and its height was 60 *cm* where basement height is 72 *cm* (1/6thless). And there was also a practice of providing an 'Elanthiṇṇa' below the Verandah which also acted as an apron preventing dampness entry etc. Sometimes it is provided as an additional basement below the main basement also to serve the same purpose usually in Temples and palaces to get more height for the building. Here it may be noticed there are some deviations from theory and practice regarding the Upapīṭham. Practically Upapīṭham given in texts has been merged with the basement and then a sub-structure was usually provided with 18 cm height. Indira Gandhi centre for Arts conducted a conference specifically on 'Theory and Practice in Vāstu vidya' in Calicut University (2000) to discuss the conclusiveness of theory and divergence of practices. Much local knowledge also has contributed to the practices. For instance, there is no statement in any of the texts regarding allowing a time gap between the commencement of superstructure construction after the completion of foundation and basement. Studies on this aspect in the Cochin University of Science and Technology under the title 'Effect of Stage Loading on Cochin Marine clay (Rajasekhar, 1991) have been done.

The above result reveals that certain Nāṭṭarivu (indigenous knowledge) has also some validity, which could be proved scientifically.

7.5 CONCLUSION

Soil Mechanics is one of the recent branches in Civil Engineering starting with '*Theoretical Soil Mechanics*', Karl Terzaghi (1943), but principles of geotechnical engineering were not unknown to India All Vāstu texts have a chapter on *'Bhūparīkṣā'* meaning testing site (soil). In site selection processes, some engineering properties of soil were also analyzed and investigated though in a rudimentary form which could be seen as anticipations of several modern theories and methods in the Geotechnical engineering procedures and investigation.

With reference to IS 1892-1979: Indian Standard code of Practice for subsurface Investigation for Foundation, the parallels between traditional approach in site reconnaissance and site investigation and current practices could be recognized easily.

The soil investigation in Vāstu mainly includes the following:

a) The site must be ploughed and top soil examination must be done. to ensure that the site was not earlier reclaimed nor used for disposal of refuse. Presence of ash, charcoal, and pieces of bone, husk, hair, worms, white ants and central depression of the plot is an indication of disposal area/reclaimed area.

b) Take a trial pit (size 72 cm x72cm x72 cm), at centre and back fill it using the excavated earth. Excess spoil will ensure that existing soil is well compacted.

c) Take a pit and fill it with water and carry out a percolation test and while water percolates vortex formation shall be in the clockwise direction. Presence of subsurface toxic gas were tested by lighting wicks in pits (TS).

d) At the centre and corners of the proposed house drive wooden pegs as specified with an iron hammer and assess the strength.

e) Determination of density of soil.

f) Vāstu has its own classification of soil and ‘Sngidha’ type soil always preferred.

With regard to foundation tradition had always looked for an original ground having good bearing capacity. Thus it required only shallow foundation from a modern perspective. However traditionally soil was excavated up to rock or ground water level or at least 2.2 m depending on the importance of the structure and height of the structure. After excavating the entire area was to be refilled with engineered well graded gravel sand and soil mix sufficiently rammed after watering. The basement stared from this ‘improved ground’ with a layer of stone or laterite. Thus traditional structures were devoid of ‘foundation’ when compared to present practice.

Ongoing through the stipulations it could be seen that there is a scope for developing and standardising these tests so that it can be used for residential and other light structures having one or two floors.

CHAPTER 8

INFLUENCE OF MEDIEVAL MATHEMATICS

8.1 INTRODUCTION

India's glory in mathematics commences with '*śūlbasūtras'* for historians in Mathematics, but for others it starts with the 'big zero'. Invention of decimal system and identification 'zero' as a numeral is one of the land marks in the history of mankind. Laplace (1749-1829), the famous Mathematician has rightly put this: '*The ingenious method of expressing every possible number using a set of ten symbols* (*each symbol having a place value and an absolute value*) *emerged in India. The idea seems so simple nowadays that its significance and profound importance is no longer appreciated. Its simplicity lies in the way it facilitated calculation and placed arithmetic foremost amongst useful inventions. The importance of this invention is more readily appreciated when one considers that it was beyond the two greatest men of Antiquity, Archimedes and Apollonius'.* The growth of Indian mathematics was thought to have ceased with Bhaskara-II (11^{th} Cent.) due to political unrest in the North India. But it continued in the south especially in Kerala.

8.2 KERALA SCHOOL OF MATHEMATICS

Kerala witnessed an unprecedented advancement in Mathematics during 1300-1700 and further sustained its glory up to 1850. Kerala mathematics could transcend from finite systems of Mathematics to infinite analysis, GG Joseph (2000). Saṅgamagrāma Mādhava (c.1340-c.1425) could formulate the following series expansions centuries before Gregory (1638-1675), Newton (1642-1727), Leibnitz (1646-1716), Wallis (1616-1703) etc., and this duly acknowledged by European scholars in early 19^{th} century itself, John Warren (1825) and Charles M Wish (1835),

$$\tan^{-1} x = x - \frac{x^3}{3} + \frac{x^5}{5} - \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Iṣṭajaya…)}$$

$$\frac{C}{4D} = \left(\frac{\pi}{4}\right) = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} - \frac{1}{11} + \ldots\ldots\ldots\ldots \text{ (Vyāsevāridhinihate)}$$

$$\frac{\pi}{16} = \frac{1}{1^5 + 4.1} - \frac{1}{2^5 + 4.3} + \frac{1}{3^5 + 4.5} - \frac{1}{5^5 + 4.7} + \ldots \text{ (sama pañcahataya…)}$$

$$Sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \ldots\ldots\ldots \text{ (Nihatya cāpavargeṇa cāpān tatat…)}$$

$$Cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \frac{\theta^6}{6!} \ldots\ldots\ldots\ldots\ldots\ldots \text{(Nihatya cāpavargeṇa rūpam tatat…)}$$

for π, Sine, Cos and Tan functions centuries before Gregory, Newton and Lebitiniz. Rajagopal and Rangachari (1977).

Since Kerala existed tucked between the mountain ranges and Arabian Sea, in the south-west tip, was politically undisturbed during this period unlike Northern India, which was facing continuous threats and attacks from outside. With fertile land blessed with forty rivers and two monsoon seasons and tropical climate made Kerala a well-known location for pepper and other spices from time immemorial. Thus the rulers of this part of the country were immensely rich through spice trade and were magnanimous and keen in offering boundless patronage for intellectual pursuits. Thus during the medieval period, Arts, Music, Drama, Literature and Sciences like Mathematics, Astronomy, Vāstuvidya and Ayurveda flourished with no comparison to other parts of the country.

With regard to Mathematics and Astronomy, remarkable contributions were made by Mādhava (c. 1340 – c. 1425), Vaṭeśśeri Parameśvara (c. 1380–1460), Dāmodara (c.1410-c.1500), Kelallūr Nīlakaṇṭha (14 June 1444 – 1544) Jyeṣṭhadeva (c.1500 – c. 1575) Citrabhānu (16th century) Śaṅkara Vāriyar (c. 1500 – c. 1560), Acyuta Piṣāroṭi (c. 1550 – 7 July 1621). Putumana Somayāji (c.1660-1740), ŚaṅkaraVarman (1784-1845) etc. In the field of Mathematics, Infinitesimal Analysis and the concept of Calculus were the important contributions from historical point of view (Parameswaran,1990). In the history of mathematics and astronomy, these contributions from Kerala are currently studied under the title 'Kerala School'. This study has gained worldwide acceptance and acclaim with the Exeter University in UK conducted this study under the name Āryabhaṭa group under the leadership of Dr. Almeda and Dr. George Joseph and further publication of the book 'Kerala Mathematics, History and its possible transmission to Europe' (Joseph, 2009). The mathematical and astronomical inventions served the main purpose of refinement of astronomical theories, its computational techniques and revalidation, revision, reconstruction of various astronomical constants required for the calculations of true longitudes of Sun, Moon, planets and nodes to predict exactly the day-to-day movements of these heavenly objects with respect to a given place and time and predict celestial phenomena like eclipses, conjunction of planets etc. accurately. In the West also, the development of mathematics in the seventeenth century was initially related to Astronomy and it got shifted to other areas of science and technology only later. In particular, the calculus played an important role in deriving many results in Physics and Engineering during nineteenth century once Calculus got prime acceptance after Cauchy (1821) wrote *Coursd'Analyse* (Rajasekhar, 1999).

It is to be investigated in a similar manner whether the ‘Kerala School’, where Calculus originated, had made any impact on Engineering and Technology and whether it triggered any research in other applied sciences. By and large, it is generally understood that no remarkable technological advancement was made and the ‘invented mathematical ideas’ remained within the mathematical and astronomical sphere at theoretical level. The class structure which prevailed in the society during the period prevented the exchange of knowledge and ideas between different sections of society. Those who work with hand and those who work with head were not connected in the sharing of knowledge. The only notable exception to the above compartmentalization may be the field of ‘Architecture and Building Science’. This field broke all the barriers of so called ‘caste’ or ‘class’ structure and even the lower tier worker involved in construction were made literate in Sanskrit. They were taught Sanskrit to get them trained in the ‘Building Science’. This might have been an intentional move to attain perfection in construction and to ensure the desired construction quality. This has also had far reaching social impact.

Incidentally prominent writers of Vāstuśāstra during this period were closely associated with ‘Kerala School’ as evident from the fact that Cennās Nārāyaṇan Nampūtiripāṭ (b.1428), the author of the most renowned text, *‘Tantrasamuccaya* (TS)’ the code of rituals for Kerala temples, has included a chapter on Vāstuvidya depicting various aspects of temple construction. The author’s knowledge in Mathematics and Astronomy is evident from this chapter. He was a contemporary of Parameśvara (1360-1460 AD) who introduced the revolutionary system of ‘Dṛggaṇita’ in Indian astronomy. The author of *Manuṣyālacandrikā* (MC), Tirumaṅgalattu Nīlakaṇṭhan (b. 1510) was a student of the famous mathematicianastronomer Nīlakaṇṭha Somayāji (1444-1544 CE) who wrote *Tantrasaṅgraha* (1500CE). He was also a colleague of Jyeṣṭhadeva (b.1510 CE) who wrote *Yuktibhāṣa*. Another popular treatise named *Śilparatna*-SR (1635 CE) was written by Śrīkumāran. He also authored a text called '*Bhāṣāśilpiratna'* in Malayalam verse which is roughly a concise translation of the former text. Śrīkumāran had also association with Trikanthiyur, the seat of learning established by Nīlakaṇṭha. Thus it could be inferred that there was close association with the Mathematicians and they themselves had acquired ample knowledge in Mathematics and Astronomy. This should have had definite impact on the epistemological and philosophical approach to the building science as well.

Writing new books on the subject itself is an indication of some innovation that had evolved in the field. Traditionally, new books were written only when new ideas/approaches were to be presented, otherwise scholars ventured to write only interpretations on well-known texts, called 'vyākhyāna' to exhibit their command over the subject. Both MC and SR refer to TS as the prime text which indicates that TS had introduced new concepts that were not seen in earlier texts.

Examining the history of modern Civil Engineering in the West, the advances made in the field of Mathematics have remarkably influenced by the development of Structural Engineering. The scientist who expounded column buckling theory was a mathematician and Carl Terzhaghi who is considered as the father of soil mechanics was a Physicist. So also was Bernoulli.

The development of modern engineering theories started during the renaissance period and most of the modern structural concepts came into existence during the latter half of the eighteenth century and formalized during the latter half of the nineteenth century. In Europe, many magnificent buildings and large structures were built during this period which warranted the need for Structural Engineering and thus progressively by research and systematic documentation. Structural Analysis and Design developed as a science and technological tool to meet that requirement. Until such time, there was no textual back-up known to have existed in the West to design and detail various structural elements of buildings. As stated earlier, in Indian sub-continent and South-East Asia the situation was different. Many astonishing structures were built between Eighth century and Seventeenth century, and these were built according to the principles and rules cited in Vāstu texts.

8.3 TRADITIONAL ARCHITECTURE OF KERALA

As cited earlier, traditional Kerala Architecture is unique in many aspects when it is compared to the architecture styles in the rest of Indian sub-continent; so also is the Vāstu literature. The development of Kerala style of temple architecture has taken place in around 200 CE subsequent to the migration of people from Northern India. This happened as a part of establishing sixty four grāmas (settlements) from Southern Karnataka area in the North to Chenganoor in the south extending to about 600 kilometres in Kerala. Three stages can be traced in the evolution of Kerala architecture. The first stage began from 4th Century to 10th Century, the second stage from 10th Century to 13th Century and the last stage subsequent to 13th Century. During these stages, when a new style suited to the geography, climate, need and raw material availability was developed, there was also a need for new reference books. As occurred in other spheres of knowledge i.e. Mathematics, Astronomy, Ayurveda etc., there has been revitalization of Vāstuśāstra also. Most evidently, the use of rock and stone masonry was reduced and style became more timber intensive and airy. Some of the Indian Vāstu literature is as old as Vedic texts. The texts available on the subject were numerous as evident from the mentioning of more than twenty five reference texts in the preamble of MC. However as mentioned above there were requirements for new reference texts as new ideas and concepts were being evolved. One of the oldest writings of Kerala, that too in Malayalam, may probably be Pūtayūrbhāṣa (c1320). Further this was refined and included as a chapter in the Codes for Rituals in Kerala Temples called *Tantrasamuccaya* (TS) written by Cennās Nārāyaṇan Nampūtiripāṭ (b. 1426 CE). All local trends and practices have been successfully embedded by Cennās in TS. Subsequently Tirumaṅgalatt Nīlakaṇṭhan (b. 1500 CE) and Śrīkumāran (c.1590) wrote MC and SR incorporating developments in the school of thought put forward by *Cennās*, in TS. In this we can notice parallels in the Astronomical developments in Kerala which commenced with Dṛggaṇita in the same period. After TS, the second and third stages of Kerala Architectural pursuits were mainly according to TS and MC and SR produced based on same philosophical approach. This could also be considered under the umbrella of 'Kerala School'

When we compare the Vāstu stipulations depicted in *Bṛhatsaṃhitā* (6th Cent.) or *Samarāṅganasūtra*, there are remarkable differences in approach and treatment on the subject of Vāstu. Even when it is compared with *Vāstuvidyā*, which is referred in MC. With TS, 'digyoni' concept based on perimeter was firmly established and meticulously followed from that period.

With the modern studies based only on the structural behaviour, the classification of vertical load carrying members as pedestals, short columns, intermediate columns and long columns came into existence. It is evident from *Matsyapurāṇa*, *Mayamata*, *Bṛhatsaṃhitā* etc., the upper limit of short column as 11 or 12 was very well known, but what astonishes us is the lower limit that is specified in *Manuṣyālacandrikā* and that too not seen elsewhere. The ingenuity lies in the fact that MC has specified the range from 4 to 11 indicating less than 4 is not a column.

As stated earlier for classifying a column in to pedestal, short column etc. and to specify the limits, clear understanding of structural behaviour and mathematical analysis are imperative as clear from the history of modern structural engineering discussed earlier.

Accordingly,

> stambhoccābdhīṣu ṣaḍbhūdharavasunavadigrudrabhāgaikataḥ syāt
> stambhābdho vistṛtistadavasunavadārudrāṃśahīnogratāraḥ|
> daṇḍāpyaścāyam etena ca kuhācidatho mīyate dārukkṛptau
> kuḍaīstambhāgratāroƒpyatha tadavayavākalpane daṇḍasaṃjñaḥ || (MC 5.24)

Literal translation*: The bottom width of the pillar will be 1/4, 1/5, 1/6, 1/7, 1/8, 1/9, 1/10 or 1/11 of the height of the pillar and the top width will be reduced by 1/8, 1/9, 1/10 or 1/11 part of the bottom width. This (top width) is called danda. Then by this, the dimensions of timber works are computed in some place. The top width of the pillar in the wall (viz;pilaster) is named as the danda for its decorative works.*

Lateral dimension shall be 1/4, 1/5, 1/6, 1/7, 1/8, 1/9, 1/10 or 1/11 of its height.

Referring to modern building codes in this context, as per the clause 25.1.1 of IS 456-2000, Indian Standard: Plain and reinforced Concrete -Code of Practice, a column or a strut is a compression member, the effective length of which exceeds (3) three times the least lateral dimension and hence when L/D is less than 3 it will be under the category of Pedestals and not columns. MC has precisely set the lower limit as 1/4.

As stated above, the rule in the MC stating both the lower limit as 4 and upper limit as 11 is amazing. Is this just a coincidence? Any chance that Tirumaṅgalatt Nīlakaṇṭhan carrying out a mathematical analysis to find the above limits. The possibility cannot be ruled out though derivation for the slenderness limits are not stated in any available medieval Vāstu texts. There are instances where the scholars of Kerala School using Calculus for deriving a curve for profiling a vessel for making a globe rotating synchronous with time (equivalent to a water clock). While interpreting the Verse 22 in *Āryabhaṭīyam*(AB)(Part III: Golapāda)

> kāṣṭhāmayaṃ samāvṛttaṃ samantataḥ samaguruṃ laghuṃ golaṃ
>
> pāratatailajalastambhramayet svadhiyā sa kālasamam| AB: 3:22

Literal translation: *A perfectly round sphere (globe) made of light weight uniformly dense wood shall be made to rotate using mercury, oil and water* (Sooranad, 1957)

Nīlakantha (1454-1544, the Guru of Tirumaṅgalattu Nīlakaṇṭhan (author of MC), states as follows in his famous *Āryabhaṭīyabhāṣya* (ABB)

> kāṣṭhā mayaṃ na lohādimayaṃ … svayamapyabhyūhya jñeyaḥ| (ABB2:22)

Here the requirement is to profile a vessel with a bottom opening so as the water level in the vessel falls synchronous with time. (Note that in a cylindrical vessel water will initially fall quickly and then it will slow down due to reduction of head) For this NS suggests to profile (*pariṇāhabhedaḥ kartavyaḥ*) the vessel .He adds that "*asya yuktiḥ svayamapi jñātuṃ śakyā, gaṇitayuktivatdurvijñeyatābhāvāt*" which means that the logic (required in equation) in this context is also is derivable (by us) as in the case of any other mathematical problem. Thus it becomes a problem in Hydraulics and applied mathematics. Let us derive the equation for profiling.

Assume a circular vessel with radius R at any height h

Then:

Velocity of draining water $v = \sqrt{2gh}$ where g acceleration due to gravity and h head (height) of water in the vessel.

Let 'a' area of small opening at the bottom though which water drains. And Cd be the coefficient of discharge.

Then water drained out in time dt = $\Delta Q = C_d.a,v.dt = C_d.a.\sqrt{2gh}.dt$ .... (1)

Let drop of height in water lever be dh and radius at that height be R

Then $\Delta Q = \pi R^2.dh$. .... (2)

Equating (1) & (2)

$$\Delta Q = C_d .a, v.dt = C_d .a.\sqrt{2gh}.dt = \pi R^2 .dh \text{ ....} (3)$$

Then $$\sqrt{h} = \left[\frac{\pi}{C_d .a.\sqrt{2g}} \right] .R^2 . \frac{dh}{dt} \text{ ....} (4)$$

But in order to achieve synchronisation, $\frac{dh}{dt}$ shall be constant.

Then $$\sqrt{h} = \left[\frac{\pi}{C_d .a.\sqrt{2g}} \right] .R^2 .C \text{ ....} (5)$$

From Eq.5

$$h = \left[\frac{C \ .\pi}{C_d .a.\sqrt{2g}} \right]^2 .CR^{4.} \text{ ....} (6)$$

$$R^4 = \left[\frac{2g.a^2 .C_d{}^2}{C^2 \pi^2} \right] h = K.h \text{ . ...} (7)$$

Where K is a constant

$$R = K.\sqrt[4]{h} \text{ ....} (8)$$

That the radius (R) shall reduce with height (h) satisfying the equation $R = K.\sqrt[4]{h}$ where K is constant. Then the water level will drop proportional to time (linearly). This is the profiling (Pariṇāhabhedaḥ) implied by NS. This is a solid proof for the fact that ‘Applied Mathematics and Science’ was also under the reach of Kerala School (Rajasekhar, 2018).

Another instance is available in MC itself. Regarding the determination of true cardinal directions (Geographical East and North), several methods have been discussed in several texts, of which MC states only one method. This method suggests a correction with respect to a popular method to make the E-W and N-S line more precise. The validity of the correction is established here and it indicates the longing for Kerala School for precision. This thirst only made the Kerala School to find a high precision values for π, sin, cos tan ,radian etc. Āryabhaṭa had given the value of π =3.1416 and had given a table for computation of R Sine and R Cosine assuming the value of Radian as 3438’. In the course of preparation of high precision table Madhava transcended from finite to infinite surpassing all his predecessors and discovered many series expansions just for improving two values shown above π =3.14159265359 and Radian as $3437^{'}44^{''}48^{'''}22^{''''}$ to compute high precision table *‘śreṣṭhānāmavariṣṭānām*…’etc. (Rajasekhar, 2014). This was the level of accuracy Kerala Mathematicians were seeking in the 14th Century which matches with modern value (Loney, 2002). Then there is no wonder that they will formulate accurate method for declination correction for the different in angle between forenoon shadow and afternoon shadow. The idea and necessity of correction was known to ancient writers as *Kātyānaśūlbasūtra* itself says about it and later Vāstu texts like *Mayamata* quotes the same also. This was a correction table month wise at the interval of 10days.

As mentioned in previous chapters, the principle orientation is one of the main canons of Vedic Architecture, or Vāstuśāstra, orienting the building in the cardinal direction was meticulously followed as a traditional practice in Indian subcontinent. With the advanced technologies like GPS, the accurate determination of cardinal directions at any location is now very simple and easy, but in the past it was not so. Moreover in Kerala itself there are temples which have been perfectly placed in same latitude miles apart. For instance Triprayar Sree Rama Temple and Arattupuzha Sastha Temple are located face to face as per the local belief. As a part of this research, the latitude of the temples which are constructed nearly 14 Km away was checked. If placed face to face in the earth means, the latitude shall be same as earth is a globe. The results were positive, the latitudes and longitude are (10·..41638 N, 76.22948E; 10.41401N, 76.11567E) for Arattupuzha and Triprayar respectively. The same is the case with Vaikom Mahadeva Temple and Ayamkudy Mahadeva Temple (9.749969N, 76.395913E; 9.750022N, 76.472878E). The traditional method of determining the latitude (Aksha) is also from gnomon shadow. The mathematics behind it and the corrections to be applied are detailed in the chapter 'Chāyāprakaraṇam' in *Tantrasamuccaya* by Nīlakaṇṭha Somayājin (1500 CE).The level of accuracy of measurements and computations are evident from the above.

The methods for determination of the cardinal directions are dealt in detail in almost all Vāstu Texts as determination of geographic East-West line and North-South line directions was essential and mandatory for reasons cited above. One of the most ancient references to this method could be seen in the *Kātyānaśūlbasūtra* (300 BCE). Ancient texts also mention about some correction (numerical correction depending up on the month of experiment) indicating that the effect of declination affecting the result were known to them. However the sixteenth century Sanskrit text named *Manuṣyālaya Candrikā* (MC) mentions a unique method of determining the cardinal directions. This method is unique as it contains a simple procedure for fine-tuning the result obtained from the usual procedure for determining the East-West. The rectification or refinement as depicted in MC is not seen elsewhere. Even though the error in the usual procedure is very minute, there is a need for such correction scientifically. This paper deals with this method of determination of the cardinal directions depicted in *Manuṣyālaya Candrikā* (MC). The paper also discusses the rationale behind the rectification process. Its mathematical validity is also established.

8.4 RULES FOR DETERMINATION OF CARDINAL DIRECTIONS

The traditional method of determination of geographical North is called śaṅkusthāpana**.** Śaṅku in Sanskrit means a gnomon. This is detailed in many Vāstu texts as mentioned earlier and the procedure is same in all texts. The procedure is that tip of the shadow of a vertical post in a plane (flat) ground touching a circle drawn around the post, is marked in the morning (in the West) and after noon (in the East). The line joining the points on the East and West will be the true East-West line and perpendicular of this line will be the North-South line. As mentioned earlier, *Manuṣyālaya Candrikā* (MC) has given a refinement and the procedure is as follows.

The second chapter of MC deals with the topic of determining the cardinal directions. This topic is usually referred to as '*Dikpariccheda'* (section on directions) or *Diknirṇaya* (Determination of Directions). The first verse in this chapter, says about leveling the ground as a part of conducting the experiment and making of the Śaṅku (gnomon), Refer Fig. 8.1.

yantreṇāvanatādinā ca nipuṇo yadyāṃmbusaṃpūraṇe
morvīcārusamīkarotvathadṛḍhaṃ śaṅkuṃ karārdhāyatām |
mūledvyaṅgulivistṛtaḥ kramavaśād agre tadardhonmita
vyāsaṃ vṛttataraṃ sarojamukulākārāgramākalpayet || (MC 2:1)

Literal translation: *One who is an expert in the experiment shall level the ground perfectly using the avanata (A-Frame) or using water. Then he shall make a strong and rigid śaṅku(made of woodhaving an effective length equal to half a Hasta and bottom diameter 2 Aṅgula , gradually tapering in to 1 Aṅgula at the top and finally top is finished in the shape of a lotus bud.*

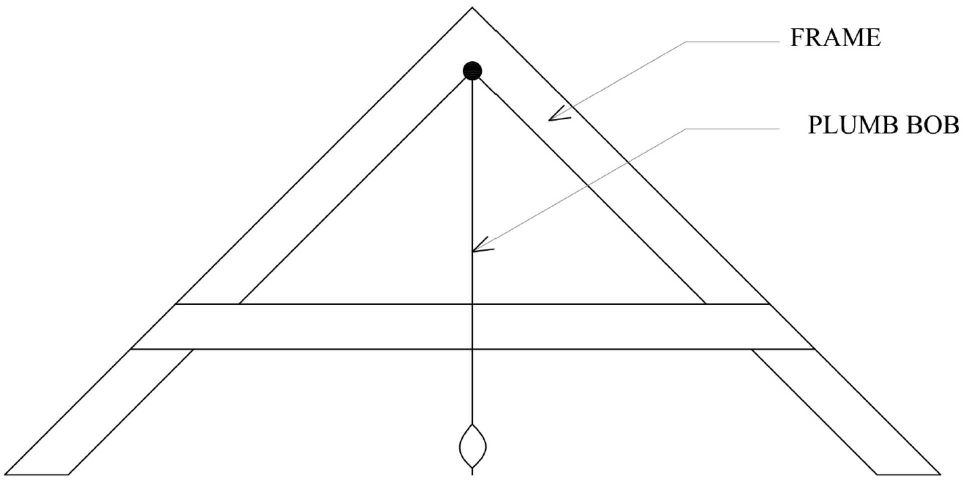


Fig. 8.1 Avanata – for fixing floor levels

The second verse depicts the process of fixing the śaṅku at the ground

> śaṅkudīrghayugasammitasūtreṇākalayya parivṛtya savṛttam |
> vṛttamadhyamavadhārya sasūkṣmaśaṅkumātra tu dṛḍhaṃ niveśayet || (MC2:2)

Literal translation:'*Draw a perfect circle with radius equal to twice the effective height of the śaṅku. Then erect the śaṅku at the centre of the circle with precision'.*

The third verse states:

> śaṅkuchāyāgrabhāge tvavahitahmadayo vṛttalagne*f*ṅkayitvā
> prāṇānte paścimasyāṃ diśi taditaradiśyevamevāparāhne |
> pāścātye*f*nyedyurapyaṅkanam api ca vidhāyāṅkayoretayoḥ
> apyantarbhāgatribhāgena ya tu gatadināṅkaṃ tadeveha sūkṣmam|| (MC2:3)

Literal translation: *'Watch calmly the shadow and mark, intersection point of the tip of the shadow with the circle in the morning on the western side and in the afternoon on the Eastern side, the point of intersection. On the next day also the point of intersection shall be marked on the western side. After that trisect the angle between the two marks on the west and mark the one-third nearest to the previous day's mark. This is the corrected position (West)'.*

The fourth verse describes the determination the East-West line:

> pūrvāparedyuḥ prabhavāṅkayugmamamevaṃ susūkṣmaṃ parikalpitaṃ yat |
> tadaṅkayugmāhitasūtrameva pūrvāparāśāprabhavaṃ susūkśmam || (MC2:4)

Literal translation: *'After marking the points (as described above) on the day and previous day, the line joining the two points will produce the true East-West line'.*

Next verse describes the method to correct its perpendicular to determine the North-South line:

> evaṃ kṣetrasya madhyameṣu vihitamiha yadbrāhṛsūtraṃ tadāhu-
> stanmadhyeʄnyonyamantaragatam atha racayed vṛttayugmaṃ ca dhīmān ||
> tadyogāt tiryagudyajjhaṣajatharasusaṣumnādhvanāsūtramekaṃ
> yāmyodaggāmi sūkṣmamaṃ racayatu yamasūtraṃ tadityāmananti || MC2:5

Literal translation: *The (E-W) line thus marked at the centre of the site is called Brahma sutra. In the middle, two circles intersecting each other shall be constructed. The line drawn thorough the fish* **(***shaped figure) thus formed will produce the Yama sutra (N-S) line.*

In a levelled ground where there are no obstructions, draw a circle having 72 *cm* (double the height of Śaṅku could be a generalised statement as (*Mayamata* says) radius and fix a gnomon having height 36 *cm* above ground at the centre of the circle. This shall be made of wood with 6 *cm* diameter at bottom and 3 *cm* at top and the tip tapered in to a shape of lotus bud. Watch the shade of the gnomon.

Suppose the experiment is conducted in Kochi (Ernakulam, Kerala, India on 14th July, 2018,the tip of the shadow will touch the circle at 8: 09:34 (AM) and 16:51:53 (PM) and on the next day 8:08:40 AM. The line joining the West and East points will generate the East –West direction. But markings are made in the morning and evening. Due to the phenomenon of declination (Ayanam in Sanskrit) of the Sun, which is the apparent movement of the Sun in the North and South with respect to the celestial equator, the position of the shadow (angle that shadow makes with the true E-W line) changes every day or rather changes continually with respect to time.

The declination on any day after is given by the following equation:

$$\delta \approx \omega \cos\left(360.\left(\frac{N+10}{365}\right)\right)$$

Where δ is the declination on any day (in degrees), ω maximum declination, N number days elapsed from January first.

This change in the angle of declination will cause deflection of the shadow also. That is the reason why MC recommends a correction.

From the experiment stimulated, it could be seen that the time elapsed between the instant shadow touches the West side of the circle and East side of the circle is 8 h and 42 *m*. This will vary from season to season. Average time elapsed could be taken as eight hours i.e. roughly one-third of a day. During this time period, due to declination change, the shadow gets shifted. That is the reason for the need of correction. By marking the position of the shadow on the very next day we are getting the position of the shadow after twenty four hours. The East mark corresponds to a shadow at 16:51:53 Hrs. Actually we need a corresponding point at West side also. But we have mark at 8: 09:34 Hrs on the same day & 8:08:40 AM on the next day. Hence by interpolating these points, actual point can be obtained. As cited earlier the change of declination is not a linear function and hence the rotation of the shadow is also non-linear. However from the following we can approximate the variation for a day as linear.

Let the declination counted from winter solstice (December) be expressed in radian measure as

$$\delta \approx \omega \cos\left(2\pi.\left(\frac{N}{365}\right)\right)$$

Where δ is the declination on any day (in Radians), ω maximum declination (Radians), N number days elapsed from December solstice.

Then declination on the first day experiment

$$\delta_1 \approx \omega \cos\left(2\pi.\left(\frac{N}{365}\right)\right) \text{..........} (1)$$

Then declination on the second day experiment

$$\delta_2 \approx \omega \cos\left(2\pi.\left(\frac{N+1}{365}\right)\right) \text{..........} (2)$$

Equating (1) and (2).

$$\therefore \delta_1 - \delta_2 = \omega\left\{\cos 2\pi\left(\frac{N}{365}\right) - \cos 2\pi\left(\frac{N=1}{365}\right)\right\} = 2.\omega.\sin 2\pi\left(\frac{N+1/2}{365}\right).\sin\left(\frac{\pi}{365}\right)$$

$$\text{As } \delta_1 - \delta_2 \to 0$$

$$\delta_1 - \delta_2 \approx \frac{2\pi\omega.}{365}.\sin 2\pi\left(\frac{N+1/2}{365}\right) \approx \frac{2\pi\omega.}{365}.\sin 2\pi\left(\frac{N}{365}\right) \approx$$
$$\frac{2\pi\omega}{365}.\sqrt{1-\left(\delta_1/\omega\right)^2} \approx \frac{2\pi\omega}{365}\left\{1-\left(\frac{\delta_1}{\omega}\right)^2\right\} \text{..........} (3)$$

Also

$$\delta_1 - \delta_2 \approx \frac{2\pi\omega.}{365}.\sin 2\pi\left(\frac{N+1/2}{365}\right) \approx \frac{2\pi\omega.}{365}.\sin 2\pi\left(\frac{N+1}{365}\right) \approx$$
$$\frac{2\pi\omega}{365}.\sqrt{1-\left(\delta_2/\omega\right)^2} \approx \frac{2\pi\omega}{365}\left\{1-\left(\frac{\delta_2}{\omega}\right)^2\right\} \quad \text{...(4)}$$

Hence

$$2(\delta_1 - \delta_2) = \frac{2\pi\omega}{365}\left\{2 - \frac{(\delta_1)^2 + (\delta_2)^2}{\omega^2}\right\} = \frac{2\pi\omega}{365}\left(2 - \frac{2\delta^2}{\omega^2}\right) \quad \text{..................................(5)}$$

$$\Delta = \delta_1 - \delta_2 = \frac{2\pi\omega}{365}\left(1 - \frac{\delta^2}{\omega^2}\right) \quad \text{...(6)'}$$

Thus it could be derived that difference of the declination of two consecutive days is approximately $\Delta = \frac{2\pi\omega}{365}\left(1 - \frac{\delta^2}{\omega^2}\right)$ Where δ is the average declination of the days under consideration and ω is the maximum declination. (Angles expressed in radians)

Thus the movement of the shadow is also proportional to the above constant and hence dividing the arc between the consecutive days marks linearly proportional to the time elapsed is rational.

Here since the height of the gnomon is 36 *cm* and the radius of the circle is 72 *cm* approximate time between the shadow tips touching the circle at West and East will be 8 hours (Approximate) and hence dividing it in to 3 (three) parts can be thus be validated.

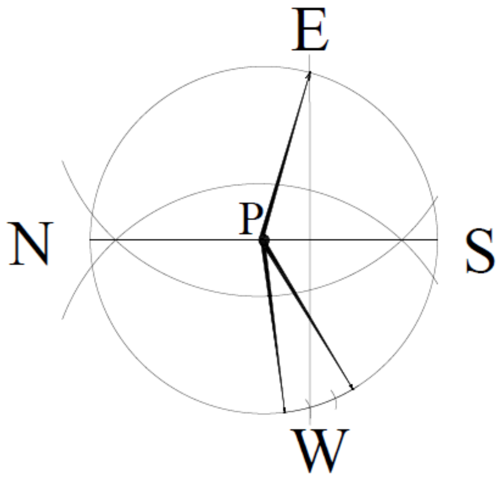


Fig. 8.2 Determination of Cardinal Directions

Thus it can be proved that the method of determination of the true cardinal direction depicted in the traditional Indian texts is scientific and rational. The method of marking the points where shadow of a gnomon installed at the centre of plane ground, enters and exits the circle drawn with a radius double the height of gnomon and joining them to get the East-West line. MC proposes a correction by marking next day's shadow and trisecting the angle made between the previous day's shadow on the West and consider the corrected location of shadow the nearest trisected point from the previous day's shadow tip (Refer Fig. 8.2). The rationale of this correction is derivable mathematically as depicted above. Astonishingly the correction proposed in MC (*Manuṣyālayacandrikā*) reveals that there was a process of review and revalidation in the tradition producing coherent refinements.

Tantrasamuccaya has given another method which is also not seen in any other text. It says:

> sākṣe śaṅkumināṅgulaṃ samatale kṛtvā pṛthakkālaja-
> cchāyāgrā racitatribinduparivṛtyotpādya matsyadvayaṃ |
> tat sauṣumna sirotthasūtrayugayogācchaṅkumūlāntimaṃ
> sūtraṃ nyasya susādhayetadyamadhaneśāśe tataścetare || (TS 1.21)

Literal Translation: *Erect a śaṅku in a levelled open ground. Having a height of 12 A. Draw three concentric circles having the radii of 12A, 24A and 36 A. Let the shadow tip cut at three points in three circles. Draw circles at these points having 12 A radius each forming two fishes. Join the ends of these fishes to cut at a point on Northern side. The intersection point when joined to the bottom of Gnomon will give exact N-S line.*

The above method is an exemplary method. Reinforcing this conclusion that lot of research studies were going on in that period , some later texts like *Śilparatna* (CE1635) on the same subject has come up with some alternate method for accurate determination of direction using theoretical calculation of the offset of the shadow. *Mayamata* recommends to make the śaṅku using Ivory or wood and categories of timber are also mentioned. This is to ensure no bending warping etc happening while exposed to the Sun for long duration.

Time of entry and exit of shadow in to the circle and duration:

On the solstice days and Equinox days the duration will be as follows:

Table 8.1 Determination of duration

Date	Time at which shadow touches the circle (W/E)		Duration
	Time –FN	**Time AN**	
March 21	8:19:55	16:44:36	8:24:41
June 21	8:05:23	16:47:48	8:42:25
September 22	8:05:20	16:29:57	8:24:37
December 22	8:42:26	16:04:50	7:22:24
Average Time elapsed between entry and exit of shadow in to the peripheral circle(Location Ernakulam , Kerala, India)			8:13:12

As mentioned earlier, astronomers, mathematicians and Vāstu experts had close associations and most of the scholars had studied all the three subjects. Tirumaṅgalatt Nīlakaṇṭhan's colleague has written the very popular Mathematics text *Yuktibhāṣa* (1530 CE). In this text while deriving the infinite series expansion for PI, example for demonstrating the properties of similar triangle has cited the relation between the length of the collar pin slot and the rafter in a square pavilion. The literal translation of the portion is as follows:

"Then there is a second antecedent figure (triangle). For that E-W line itself is the Base. From the end of the Base, two segments together, along the side of the square, is Height or opposite side. The second radial line from the centre of the circle becomes Hypotenuse. Thus is the second antecedent figure (triangle). Then consider, the consequent figure corresponding to this. The line from the end of point of the first radial line, perpendicular to the second radial line, is the Base. From the meeting point of this Base to the end of the radial line is the Height. The second segment in the side of the square is the hypotenuse. This is the second consequent figure

(triangle). When the second rafter becomes the antecedent hypotenuse, the two spans of the rafters together becomes the antecedent height (opposite side of the right triangle). Hence the length of the second rafter will have more length than the first rafter. Proportionately the length of the slot for the wooden pin also will be more. That (the length of the slot) will be the hypotenuse of consequent figure (triangle) and will be parallel to the eave line, which is the opposite side of the antecedent figure (triangle). How the inclination of the rafter and the inclination of the slot are varying proportionally, in the same way the antecedent figures (triangle) and consequent figures (triangle) considered here are also correlated. Here at the end of the E-W line, the second segment in the side of the square is multiplied by the radius, which is the base of the antecedent figure (triangle) and divided by the second radial line (which is the fourth proportion). The result is the base of the consequent figure (Right triangle). Assuming this base as opposite side (height) and then portion of the second radial line between the meeting point of this height and the centre of the circle as adjacent side (base) and the first radial line as hypotenuse there exists a third triangle here also" (Rajasekhar, 2009)

In the above, for understanding the similarity of triangles, an analogy with rafters and slits (holes) provided in the rafters to receive wooden pin (ties between rafters) is given. Here as stated earlier, a square pavilion with pyramidal shaped roof with central ridge piece and rafters originating from centre ridge piece in radial direction to seat on to the wall plate. These rafters will be usually tied by providing another square wooden piece, which is locally called Vala. These wooden pins pass through the rafters, and hence there should be holes (slots) to receive these pins. The outer most line of rafters called eave -reaper is known as vamata. The interactions between Vāstu experts and Mathematicians of those days are evident from this quote.

Another noticeable feature in Kerala Vāstu texts is that they have updated the old texts in the light of developments in Mathematics and Astronomy. For instance, value of π given in SR (1635) is 3.141592653 (104348/33215) which is correct up to 9 decimal places. Mentioning of a high accuracy value for π is definitely under the influence of Kerala School of Mathematics where Madhava (c. 1340-c.1425) gave a rapidly converging series of π, obtaining the infinite series, using the first 21 terms to compute an approximation of π, he obtains a value correct to 11 decimal places (3.14159265359). Madhava's Value for π is given in the following verse:"

> vibudhanetragajāhihutāśanatriguṇavedabhavāraṇabhāvaḥ |
> navanikharvamite vātivistare paridhimānamidaṃ jagadurbudhaḥ ||

Literal translation: *'2827433388233 units is the circumference of a circle whose diameter is nava-nikharva (900,000,000,000) units.'*

This will yield the value of π as 3.14159265359/22, which is accurate up to 11 decimal places.

8.5 CONCLUSION

The theory behind the minute correction also cannot be derived without proper understanding of the Astronomy behind it. *Śilparatna* (1635) had stated the following formula:

'Bhabhuja' is $\pm h \tan\varphi + \dfrac{R \sin\lambda . R\omega\sqrt{h^2 + s^2}}{R..R\cos\varphi}$

$\lambda, \varphi, \omega, h, s$ & R are respectively the sun's instant declination, latitude of the place, maximum declination, height of śaṅku (gnomon), length of shadow, R (Radian). A later renowned Astronomy book belonging to Kerala school, *Sadratnamālā* (1819 CE) also states same formula for finding directions.

Under the influence of Kerala School of Mathematics and Astronomy, Vāstuśāstra in Kerala which is locally known as '*Taccuśāstra'* also underwent lot of revisions and updating and a new philosophical and epistemological approach evolved in this field also. The new features were as follows:

- TS (15th Cent.) codified the newly evolved temple rituals as well as its architecture. The new code of conduct for rituals and code of practice for design and construction of structures, streamlined the temple tradition. This also influenced the residential architecture as evident from the preamble of MC where it is explicitly stated that it is written in accordance with TS.

- As the style evolved, Kerala style was more timber intensive. More emphasis was given to 'modular' type of construction which in turn helped for optimization of the use of timber as wood cutting was made easy as there was interrelation between various structural elements such as wall plates, rafters, ridge piece and reapers.

- Units of measurements were standardised in terms of absolute measurements and the same was popularised.

- A systematic approach was introduced and meticulously followed for room dimensioning, which ensured systematic and quality construction.

- In the design of column beam etc., a mathematical approach was brought in and range for slenderness ratio, span-depth ratio etc. was introduced.

- Advances in Astronomy were made use in formulating methods for finding true cardinal direction etc.

CHAPTER 9

SUSTAINABILTY AND ENVIRONMENT FRIENDLINESS IN VĀSTU

9.1 INTRODUCTION

‘Sustainability Development’ is a newly emerged worldwide concept that serves as a solution to deter the ecological and environmental impact inadvertently and carelessly caused by two centuries of industrialization. Now any developmental activity cannot be dealt without considering the sustainability considerations. Hence present-day building design and construction is closely associated with ‘Green Building’ concepts. Though the terminology, sustainable development, is recent, the concepts backing the philosophy of sustainability are not novel and not at all unfamiliar in Indian context. The holistic well-being that the Vedic philosophy advocates and the sustainable development models have many commonalities. In handling natural resources, Indian tradition was very cautious. Let it be the example of water, the *Taittirīyopaniṣad* states ‘*annaṃ na paricakṣīta. tadvratam. Āpo vā annam’* (Eighth Anuvāka). It means, ‘***Do not waste food. Deal with reverence. Water is also food.’***

9.2 ECOLOGY, ENVIRONMENT AND SUSTAINABILITY IN VĀSTU

The National building Code (2016), Part -1, Section 7 is on external development and landscape. In section 7.1.1 Landscaping depicts, *‘Proper landscaping helps in maintaining natural capacity of site for storm water management, filtration, ground water recharge and maintenance of soil structure there by contributing to soil organic matter and preventing erosion. It helps in moderating microclimate through evaporation,* *transpiration and the uptake and storage of carbon in trees and other vegetation'.* In Clause 7.1.3.1 the need for preserving top soil is emphasized as '*Healthy soils allow rainwater to penetrate preventing excess runoff, sedimentation, erosion and flooding. Soils also help clean and store water and recharge ground water.'*

Coming to Vāstu, all texts envisage proper landscaping around the buildings. As per Vāstu, there shall be a courtyard around the building (in all four sides) with minimum width of 2.16 *m*. Usually in this space no tress are allowed. The saying in Malayalam which is an adoption from a Vāstu canon is relevant here. *'Ponnukāykkunna maram āyālum, purakkaṭuttu vacu kūṭā'* which means even if it bears gold as fruits that tree in the close proximity to a house shall not be permitted. *Manuṣyālaya Candrikā* says (Sastri, 1917). *'Even if the trees are in the right location, if it is standing within a distance less than its height, even if it bears gold, shall be cut and removed'.*

The tradition is very cautious about the safety of the building and hence bans any tall trees in the proximity to avert the possibilities of its fall and possible damage to house and properties and life threats. Moreover, the roots of tall trees can pose problems to foundation and basement. The shadow of sun between 9 AM and 3 PM should not fall on the building, *'Chāyāvṛkṣasya na śubha .....'* Mayamata (Sastri, 1919).The need for sun light is also specified in Vāstu which could read in conjunction to the above.

> prācyā niṣiddho hi giri tacchāyāpyudaye raveḥ |
> yatrāpatati tatrāpi grāmādya na praśasyate ||
> grāhrā tu cottamā madhyā garhitā kanyasā mahī ||

Literal translation: *Falling of the shadow of a hill in the morning is not desirable. Hence don't locate the house on the western slope of a hill.*

In planting vegetation, Vāstu has classified the trees and shrubs in to four categories.

> antaḥsārāstu vṛkṣāḥ panasatarumukhāḥ sarvasārā śca śākā-
> ściñcādyāstālakerakramukayavaphalādyā bahissāravṛkṣāḥ |
> niḥsārāḥ śigrusaptacchadaśukataravaḥ kiṃśukādyāśca kāryā-
> steṣvādyā madhyabhāge bahirapi ca tataḥ sarvasārāstatoƒnye ||

Literal translation: *Trees with hardwood at centre like jackwood are Antassāra, those with hardwood throughout like teak and tamarind are Sarvasāra, those hard at periphery like arecanut are bahissāra and nissāra are soft throughout like murukku. The order of planting shall be Antassāra in the inner circle, then sarvasāra, then bahissāra and finally nissāra.*

Trees and shrubs are classified according to the strength of the trunk as follows.

1. Antassāra
2. Sarvasāra
3. Bahissāra
4. Nissāra

The Antassāra trees means, that which has hard wood at its centre, the examples like jackfruit tree are also given. Sarvasāra means with hardwood throughout like teak wood and tamarind. Bahissāra are with outer shell strong like coconut, arecanut and other palm trees come under this category. Here it is interesting to note that text suggests planting the trees in order of its trunk strength. In the innermost part, Antassāra, then Sarvasāra, then Bahissāra and finally Nissāra should be planted. Obliviously safety is duly considered in this guideline.

Certain trees are recommended only in certain locations (sides) with respect to the house. This is considering the botanical and other special characteristics of trees and its leaves etc. For example, tamarind is recommended in the south. From the earlier Khaṇḍakalpana (Division of Quadrants), it could been that house will be located in N-E quadrant and then S-E will left exclusively for setting funeral pyre when a member of the family expires. The tamarind usually grows high with very less branches below and with a spread-out canopy at top. Mostly the ground below tamarind tree will be left without any vegetation and grass. This helps the purpose for which the south-east is left out. There is a scope of study for similar analysis on each species of plant specified in Vāstu texts, from botanical and other characteristics, like spread of roots etc.

> pūrvasyāṃ vakulo vaṭaśca śubhado*f*vācyāṃ tathodumbara-
> ściñcā cāmbupatau tu pippalataruḥ saptacchado*f*pi smētaḥ ||
> kauberyāṃ diśi nāgasaṃjñitataruḥ plavaśca saṃśobhanāḥ
> prācyādau tu viśeṣataḥ parasapūgau keracūtau kramāt ||

Literal translation*: Elangi and Baniyan tree in the East are good, Umbura (athi) and Tamarind in the South will bestow prosperity. In the West, Arayāl and Ezhilampāla and in the north Nāga and Itti are recommended. Jack tree, Arecanut palm, Coconut palm and Mango are good in East, South, West and North respectively.*

sthāpyā mandirapāśrvapṛṣṭhadiśi tu śrīvṛkṣabilvābhayā
vyādhighnāmalakīsuradrumapalāśāśokamāleyakāḥ |
punnāgāsanacampakāśca khadirastadvat kadalyādayo
jātīnāgalatādayoƒpi sakalāḥ sarvatra saṃśobhanāḥ ||

Literal translation: *On two sides and rear of the buildings Kumizhu (Gamhar/ Gmelinaarborea),Kūvalam, Abhaya, kaṇikkonna, Nellikka, devadāru, palāśa, aśoka, candanam , punnāga, venga, campaka, Karingāli* are recommended. *Jāti, Vettila and Vāzha in all sides are good.*

In this context, National Building Code: *Clause 7.1.3.2 on Ecological design/ conserving bio diversity reads, "A diverse range of species, especially native pants cab provide habitat for native fauna including important pollinator species (for example insects, birds and bats) that are necessary for plant reproduction, including cultivation of crops. Also biodiversity in landscaping helps in retaining soil nutrients and more resistant in attack of pests. The following considerations shall be used".* The Vāstu stipulations fully conform to the above. Moreover, Vāstu has also recommended not to plant certain trees and shrubs that are detrimental to insects and pollinating agents. The undesirable plants are as given below:

kāraskarāruṣkarakaṇṭakidruśleṣmātakākṣadrumapīlunimbāḥ|
snuhīpiśācadrumahemadugdhāḥ sarvatra neṣṭā api śigrurantaḥ ||

Literal translation:' *The undesirable trees are kāñjiram, cheru, vayyankattāvu, naruvari, thānni, ukamaram, āryaveppu, kaḷḷippāla, erumakkalli and muringa'.*

Thus Vāstu texts go beyond the NBC specifications in identifying desirable and undesirable flora. Clause in NBC also specifies the following under 7.1.3.2

1. Protection and use of existing vegetation.
2. Use of vegetation that promotes a regional identity and a sense of place.
3. Conservation of native endangered species.

Vāstu has taken care of the above by desirable and undesirable trees and also by giving a list of trees that are not supposed to be cut. Moreover the system of leaving or preserving a portion of the residential plot as 'snake groves' ensured at least a portion of land is kept virgin without human intervention. It helps to keep the local flora and to some extent fauna intact. The remaining Kavu (Snake groves) in India are really hot spots of biodiversity and lungs of urbanized villages and towns. Moreover, from the list of trees to be planted, it could be seen that all trees are either useful in construction or are medicinal plants. This is a thoughtful and forceful replantation scheme that tradition has enforced.

Vāstu tradition is very conservative in selecting a tree for building purpose. Reading the rules, it can be seen that obtaining an 'Environmental clearance' from statutory bodies for cutting a tree may be easier than getting a Vāstu clearance, if one goes strictly as per the scriptures in Vāstu. The Vāstu dictions as per *Mayamata* are given below.

1. na devatālayāntasthāḥ prahatā vā na vidyutā |
2. na dāvānalasaṃlīḍhā na bhūtālayamadhyagāḥ ||

3. na mahāpathasaṃrūḍhā na tu grāmasamudbhavāḥ |
4. na ghaṭāmbubhirāsaktā na pakṣimṛgasevitā ||
5. na vāyunā na mātaṅgairbhagnā naiva gatāsavaḥ |
6. na caṇḍālajanākīrṇā na sarvajanasevitāḥ ||
7. nānyonyavalitā bhagnā na valmīkasamāśritāḥ |
8. na latāliṅgitā gāḍhā na sirākoṭarāvṛtāḥ ||
9. nāṅkurā vṛtasarvāṅgā na bhṛśaṃ kīṭadūṣitāḥ |
10. nākālaphalino grāhrā na śmaśānasamīpagāḥ ||
11. sabhācaityasamīpasthā devādīnāṃ na bhūruhāḥ |
12. vāpīkūpataṭākādiVāstuṣvapi ca saṃbhavāḥ ||

Literal translation:

Trees inside places of worship

Trees affected by lightening

Trees affected by forest fire.

Trees in sacred places.

Trees in highways

Trees in Villages

Trees that are considered as divine (by villagers)

Tress that are depended by birds and animals

Trees affected by hurricanes

Trees broken by elephants

Trees from locations where aboriginal tribes reside.

Trees respected by all people.

Trees that are supported by other trees

Trees that are broken

Trees that support white ant hills

Trees embraced by creepers

Trees with hollows inside

Trees with budding throughout.

Trees affected by insects and worms

Trees that blossom and bears fruit in odd seasons.

Trees that are in funeral grounds

Trees that are in vicinity of public buildings

Trees are in the close proximity to water bodies (wells, ponds, reservoirs etc)

The above canons regarding undesirable trees may only be sufficient demonstrate the concern of Vāstu on environmental issues. The same taboos are depicted in different texts but the essence is same.

Vāstu texts like *Śilparatna* etc. also give details of certain rituals to be conducted at the bottom of tree on the previous day before cutting that too at night (Sastri, 1922). Apart from the ritualistic aspect, this will help creatures that are residing in trees to get a warning of disturbance that is imminent.

evamanviṣya tatkarma yogyavṛkṣaṃ salakṣaṇam |

labdhvā dadyād baliṃ vidvān vidhivacchettumārabhet ||

apakrāmantu bhūtāni devatāśca saguhrakāḥ |

yuṣmabhyaṃ ca balirbhūyāt taṃ me diśata pādapam ||

śivamastu mahīputrāstubhyaṃ devāḥ saguhrakāḥ |

karmaitat sādhayiṣyāmi kriyatāṃ vāsaparyayaḥ ||

Literal translation: *The trees identified shall be saluted by prostrating before it. On the eastern side the Sthāpati shall stay in the previous night* with vrutha on Darbha *grass mat. In the morning after taking bath in auspicious time with drumming etc. shall start cutting the tree after smearing pachagavyam etc. in the sharp edge of the axe. The trees shall be cut 1 Hasta above the ground level.*

Climatology and Vāstu:

According to clause 3.2 of National Building code- (Part 8), for the purpose of design of buildings, India has been divided into five as follows depending up on solar radiation, relative humidity and prevailing winds.

1. Hot dry
2. Warm humid
3. Temperate
4. Cold
5. Composite

In Vāstu texts also, the land is classified into four keeping apart cold. Another kind of classification is also seen. The regions are calssified as Pūrṇa which corresponds to temperate zone, Supadma corresponds to warm humid, Bhadra is composite and Dhūmra is hot dry.

Another classification is Vāruṇī (warm humid,), Indrāṇī (composite), Āgneyi (temperate) and. Vāyavī (hot dry)

9.2.1 Site Selection and Environment

In the site selection process, Vāstu tradition searches for an environmentally conducive locality. Most of the desirable factors are seen summarized in a single verse in TS and due to its brevity and depth it has been included in many texts in the succeeding periods including MC and SR. The verse is

> gomātryaiḥ phalapuṣpadugdhatarubhiścāḍhaīā samā prākplavā|
> snigdhā dhīraravā pradakṣiṇajalopetāśubījodgamā|
> sā proktā bahupāṃsurakṣayājalā tulyā ca śītoṣṇayoḥ
> śreṣṭhā bhūradhamā samuktaviparītā miśritā madhyamā || MC 1:17

Literal Translation : Site should be, in a locality that is inhabited by humans, reared by cattle, occupied by flowering ,fruit bearing trees and tress of Ficus family (milky sap), with level or even ground, with gentle slope with towards East, snigdha (soil with slight oily feeling when rubbed with fingers –sandy-clay) when tapped with foot gives high frequency sound (indicating a dense soil below), with water whirling in clock wise direction, where seeds germinate quickly, with excess soil when refilled , with perennial underground water and with moderate climate ; if all conditions are satisfied the site is best, some means good and none means worst.

On examining the textural stipulations regarding site selection in the above verse that the land shall be as follows:

1. Suitable for cattle rearing
2. Previously inhabited by human beings
3. Abundant in flora especially flowering and fruit bearing plants and trees and with milky sap.
4. Elegant
5. Level
6. Sloping gently towards East direction
7. Producing a hard feeling while walking / tampering
8. With water flowing in the clock wise direction.
9. Facilitating speedy germination of seeds
10. Excess soil producing when back filled.
11. With perennial water
12. Having moderate climate.

On examination the above verse, it could be seen that most of the attributes are related to Environment. Vāstu recommends a residence in a locality previously inhabited with cattle wealth, and with moderate climate and perennial underground water. The soil and air must be such that speedy germination of seeds must happen. There must be abundant in flora especially flowering and fruit bearing plants and trees and with milky sap.

The first two points are to ensure that the environmental parameters of the land are suitable for house construction. The cattle usually rear in areas where lot of grass and water is available. More over cows are very susceptible to toxic plants and herbs, contaminated air and water. Hence an area which is freely occupied by cattle is an indication of a good environment and free of any toxicity of ground and water. This sort of analysis of land was very relevant in olden days since there was vast unoccupied land available and there was no means to test water, soil etc. In the present context, it could be interpreted as the verse points out to the testing of water, soil etc. prior to selection of land. Some texts recommend to rear cows at least for one year in the proposed land to have an assessment of land round the year to assess its performance in all seasons. Initially when a good plot with desirable qualities are found, the land must be ploughed using oxen and then watered and the navadhānya (seeds of nine category of cereals) must be sown.

Sowing of seeds and checking the germination speed was another test to check the suitability of location.

> trirātrāṅkuritā śreṣṭhā vedarātraistu madhyamā |
> adhamā bhūtarātraistu mahī syād bījavāpane || SR:4:39

Literal Translation: After sowing, *germinating in three days is most desirable*, *in four days is desirable, and five days is satisfactory*. .

The land shall be fenced (temporarily) and cows shall be made to eat all the flowers and seeds and plants thus produced. Further for one-year cows shall stay there and the process of tilling and sowing shall be repeated before concluding the suitability of site. (SR: 4:38).

The statement regarding human settlement is also relevant since there are much location which was previously discarded by humans due to various reasons mainly natural calamities like floods, Tsunami, Earthquake, volcanoes etc. The chances of recurrence of such calamities cannot be ruled out and hence a new house shall only be proposed in well occupied areas. Now also we can see that certain areas are left unoccupied by human inhabitation due to some previous history of havoc. Such area might have been occupied before and left vacant after some natural disaster. To cite an example, the island Dhanushkodi near Rameswaram in Tamilnadu could be the best. Recent floods (August 2018) also validate the statement. The early or traditional settlements including temples, churches, mosques etc. survived without any inundation and many such places acted as rescue places and assembly points.

Abundance of flowering and fruit bearing tress also ensure a good and healthy environment. The tress with milky sap indicates abundance of ground water. Ancient texts have also specified methods to explore the possibility of occurrence of ground water by examining the species of and plants growing in that area. Accordingly the land is also classified on the basis of flora and fauna in *Śilparatna*. The classifications are Pūrṇa, Supadma, Bhadra and Dhūmra. Among them, Dhūmra is undesirable. Again the land is classified as Vāruṇī, Indrāṇī, Āgneyi and Vāyavī. Good durable aesthetically pleasing and functionally satisfying constructions are possible in elegant plots only.

Next aspect cited is that land should be '*Phala-puṣpa-dugdha-tarubhiḥ*…" meaning that it should be a fertile locality with plants and trees that are producing good flowers and abundant edible fruits. More over there should be plants of Ficus family. As the Ficus family tress have a milky sap, they are generally called as *'dugdhataru'* in Sanskrit. The four trees in this family are

Ficusreligiosa, (Pepal Tree: Arayal (Malayalam) Aśvattha (Sanskrit)

Ficusmicrocarpa (Ithi (Malayalam): Plakṣa (Sanskrit)

Ficusracemasa (Athi (Malayalam): Udumbara Sanskrit)

Ficusbenghalensis (Baniyam Tree, Peral (Malayalam): Nyagrodha (Sanskrit)

These four trees together are called "Nalpāmaram" in Malayalam and have medicinal values and used widely in Ayurveda for pharmaceutical preparations. Presence of the bushy trees indicates presence of ground water and provides good shade and shelters many insects, creatures and birds.

Next aspect cited is 'āḍhya' which means elegance. The plot must be pleasing to eyes. This is quoted in *Vāstukaumudi* from an ancient text *Vāsturatnapradīpam* (Vasuachary, 2002).

> manasā cakṣuṣā yatra santoṣe jāyate bhuvi |
> tasya kuryātha gṛhaṃ sarvairiti gargadi sammatam || VK:2/1:5

Literal Translation: *One should build a house only in a plot that is pleasing to eyes and that creates inner happiness; this is endorsed by sages like Garga.*

Keeping apart the myths and religious aspects, the fundamental philosophy and logic of Vāstu is 'living harmoniously with the nature'. Vāstuvidya has clearly understood that any construction activity taken up on the mother Earth is detrimental to the natural order and hence these activities have to be controlled based on the need and be done with utmost care limiting the tapping of natural resources, to ensure its coherence with nature.

According to Vāstuśāstra, when a building is set out, the portion of the plot is said to have been occupied by an Asura called 'Vāstupuruṣa'. As building a house is most auspicious, then why then an Asura is said to have occupied the site will appear to be a paradox since Asura is usually connected with evil. Philosophically, anything which is harmonious with nature called divine or sātvik; and those against the order of Nature are evil, tāmasik. In the location where construction is proposed, when all plants, shrubs, roots, all tiny creatures etc. etc. are removed, it upsets the whole harmony nature and impacts the environment. Thus, any building activity is 'Āsura'. Understanding this, as construction activities are unavoidable for human endeavors, Vāstuśāstra proposes ways and means to minimize its impact on nature and to be harmonious with it to the extent possible.

'Vāstuśāstra has over the time become more pragmatically oriented and this has caused it to become more empirical. It is clear that many of the principles and themes found within Vāstuśāstra are resonant with those of many well-known contemporary philosophers of technology. Vāstuśāstra remains a viable and powerful way to mould science and technology within the context of design to create environments for human beings that are in harmony with nature, cosmic forces, and the universe' (Patra, 2016)

Vāstu based design is more energy efficient, environmental friendly offering more 'comfortable living'. Vāstuśāstra aims at optimizing the maximum benefits of the Pañcabhūta. The five great elements, also five physical elements, is a group of five basic elements, which, according to Indian concept, is the basis of all cosmic creation. Western Architects who work on Vāstu, mainly the Maharishi Vedic Architectural exponents like Architect Lipman look forward to Vāstu as a superior alternative for 'Green Building' initiates, which according to them is more 'trial and error' process.

Water and Sanitation in Vastu:

The importance of water and its purity have been identified from Vedic period. Pure water and polluted water has been differenced in many ancient texts mostly Ayurveda texts. Different sources of water and its quality etc. are elaborately dealt in these texts (Mrudul and Ashwini, 2016). Method of purifying water by filtering etc. are also dealt in these texts.

Tradition was very much vigilant and careful regarding the maintenance of purity of drinking water. Polluting natural water source was considered as a taboo in ancient India (Sundareswaran, 2016). Except river water, sourcing water from pond etc. which are used for bathing etc. are forbidden. Reference Manuṣyālaya Candrikā (Verse 29: Chapter 7).

vāyau vā nirṛtau ca dṛṣṭamatha snānādipānādiṣu/

prāyonaikajalaṃ nadījalamṛte'tonyal pṛthak kalpayet// MC 7:29

Literal translation: *For drinking and bathing same water should not be used, for each purpose separate (wells/ponds) shall be designed* (Cheruvally, 2016).

Ponds and wells served as prime locations of rain water harvesting and these were located in the corners where ground water recharge is easily possible (Nambooththirippad, 1999).

In the traditional building, toilets were not attached to the houses except small urinals behind bed rooms called *'Ozhvumuri'* to use as urinal. Elaborate drainage arrangements and sanitation facilities are found in archeological remnants in Mohenjo-Daro, Harappa, and Vijaya nagar. In Kerala also in Padamanabhapuram , Krishnapuram palaces attached toilets are found. In certain ancient texts like *Vastu Ratnavali* where to locate the toilets are also specified while preparing the layout of rooms (Vasuachary, 1987).

Vāstu Puruṣa-Maṇḍala.

The pink city Jaipur in Rajasthan was master planned by Rajput king Jai Singh and built by 1727 CE, in part around Vāstu-Śilpaśāstra principles. Similarly, modern era projects such as the architect Charles Correa's designed Gandhi Smarak Sangrahalaya in Ahmedabad, Vidhan Bhavan in Bhopal, and Jawahar Kala Kendra Jaipur, adapt and apply concepts from the Vāstu. The design of Chandigarh by Le Corbusier (French architect) have also corresponded to the Vāstu Puruṣa-Maṇḍala.

9.3 CONCLUSION

Vāstu tradition is philosophically committed to sustainability concepts as it is more connected with Nature. Vāstu tradition, as demonstrated in this chapter is concerned much about disturbing the ecology and always tries to be environment friendly. In material selection Vāstu always prefer natural local materials. In planning, it aims to utilize the benefits of Nature to the extent possible. Thus, there is a possibility of amalgamating the new sustainable development models, green initiatives with Vāstu to formulate an Indian version of ‘Green Buildings’ that are more sustainable and more than ‘Green’ as it is envisaged now.

CHAPTER 10

CURRENT VĀSTU PRACTICE

10.1 INTRODUCTION

The status of current Vāstu practice and its issues along with the lacuna and limitations of Vāstu as a whole are depicted in this chapter.

There are lot many differences between the Vāstu prescriptions in the texts and what is practiced. Practicing Vāstu especially in the case of residential buildings has become more peripheral and limited to certain planning aspects with respect to the location of rooms and perimeter of rooms and building as a whole. These are insisted or followed ritualistically as a part of 'Vāstu Belief System'. Many Vāstu attributes that make a house more energy efficient, environment friendly and sustainable are conveniently ignored or avoided for the sake of modern design. Such current issues are discussed in this chapter. The lacuna in Vāstu tradition and major objections regarding the Vāstu practice are also discussed in this chapter.

10.2 PRACTICING VĀSTU

Keeping apart the religious and ritualistic aspects in Vāstu, any client of the present day while opting for a Vāstu design expects knowingly or unknowingly a 'more living comfort' when compared to a modern conventional design. The modern house planning that evolved after 1960s pushed back the traditional tiled houses built mostly on 'Taccuśāstra' norms (Vāstu was not a common usage till 1990s in Kerala). All houses built after 1970s were with RCC roof and all modifications to traditional houses done to add a front portion with RCC flat slab. In this revolution the occupants lost the comfort of a tile roof house with wooden ceiling because the radiation of the slabs in summer made their life miserable. The electric fans could not help them out of this kiln effect. Many alternate options with improvisations in slabs were tried and most of them failed. On recalling the old designs, everyone had a feeling that apart from the building materials, there were also some design elements in tradition which made life cooler in the old houses. When Vāstu gained popularity in 1990s, everyone looked at Vāstu as a solution to their problem too. Unfortunately, by that time, practicing Vāstu had lost its philosophical continuum and had become more dogmatic. Most of the practitioners were mere Vāstu Pundits who were not trained in Civil Engineering or Architecture. Thus, people were not happy with the layout prepared by a Vāstu Practitioner and approached Engineers/Architects for preparing their plans. Finally, they 'showed' (presented) it to a Vāstu expert and got it vetted by them with minor dimensional modifications. Thus, Vāstu experts were reduced to a status of a blessing agency for sanctifying the plans of Architects/ Engineers. If the width of a proposed house is 800 cm and length is 1250 cm. When Vāstu expert corrects it to 800 cm × 1228 cm it becomes a 'Vāstu compliant' as far as external perimeter is concerned. It is true that such a modification is required for 'Ayādiṣaḍvarga' compliance and it is an essential part of the Vāstu belief system, the sufficiency of the same in a wide perspective of Vāstu to deliver a harmonious home is very much far away.

Thus in reality all most all the current buildings are designed with modern approach and trend and apply Vāstu rules to correct or modify it marginally to make it Vāstu compatible. These corrections and modifications are limited to the following:

- Locating the building in the desired quadrant.

- Pointing out the location for foundation stone-laying.

- Correcting the overall perimeter to match an auspicious perimeter based on the 'Ayādiṣaḍvarga' table

- Check the location of kitchen etc. whether they are in the right corners as specified in texts.

- Check the perimeter of main rooms based on 'Ayādiṣaḍvarga' Table.

With the examination of above parameters, almost all Vāstu consultants' job is over. A building design made by an Architect /Engineer is thus got endorsed by Vāstu consultants with certain minor comments as listed above. Even if we entrust Vāstu Practitioner to prepare the plan, the process is not much different. As part of the belief system, this ritualistic endorsement provides lot of psychological relief and satisfaction. But the innumerable literature on Vāstu shows that our ancestors aimed something above the current level of sheer attestation of certain ritualistic aspects. There is a need for developing a Vāstu design approach which will take care of modern needs along with taking care of the environment. For developing such an approach, Vāstu design principles and its philosophy have to be properly churned out and dynamitic design approach has to be formulated to suit the need of the day.

In the design, reconstruction and restoration of Temples, the scenario is different. Even now temples are constructed entirely based on the Vāstu principles, norms and specifications. The details of the Vaduthala Sri Ganapahy Temple (Ernakulam) which was recently completed is presented here as a case study. This was a total reconstruction of the existing temple with new plan prepared strictly as per tradition.

Apart from the concrete bed provided below the ground, the entire basement, superstructure and roofing were done in Vāstu proportions only. The basement is made from solid rock cut stones. Walls are in laterite. The roof elements like Wall plate, Rafters, Ridge piece etc. in teak wood and copper plate is provided as roof cover over wooden planks fixed on to the roof. The stonework was done by artisans from Nagercoil and wood work by carpenters from Parur Ernakulum. The interesting part is that all the detailing in various parts of the build is done as per traditions. Another noteworthy aspect is that skilled resources are still available to take up similar jobs with knowledge and they are able to accomplish the task in an exemplary manner. Thus, it can be seen that the Vāstu principles are even now applied and practiced. For such a strict adherence to the tradition, the will of the client, Vāstu consultant and the Sthapatis are all equally important and pertinent. The exquisite structure is now complete (December 2018.). Another case study is the installation of a Flag post (Kodimaram) installed recently (February, 2018), Edayakunnam temple (Ernakulum). The straight teak wood was cut from Malayatoor area after conducting all rituals as per Vāstu tradition. Then it was brought to the temple premises, seasoned and kept immersed in pure gingelly (sesame) oil mixed with turmeric, camphor etc. for seasoning and as a part of traditional anti-termite treatment. This process is called *'Tailādhivāsam'*. It was a replacement of the existing post and hence the post was placed on to the base stone originally installed at a depth of 2*m*. Then the post was erected and finally covered with the original brass shell (repaired and polished). The backfilling of the pit when post was installed previously was done with red earth (muram). This was visible from excavation. During new installation, plain cement concrete (PCC) was also used partly for backfilling. It appears that PCC was unwarranted as good quality muram was sufficient and more suitable as it will give more 'earthling' as cited in the previous chapter ensuring lightening protection as a complimentary feature due its special construction modalities. In this case study, it is noticed that when changing the specifications of the tradition even in minor aspects can affect slightly the purposes for which those stipulations are meant. Here the substitution of PCC in the place of red earth was not necessary as soil would have performed well in lightening protection as per IS Code, 3043 -1967, Lightening Protection, clause 20.6.2 and 20.6.3. Thus, it can be concluded that when the specifications are changed there should be a total assessment for the need of change. The suitably of substitution shall also be analyzed from all perspectives. The convenience, workability and easiness should not be the criteria.

In many contexts, it is also observed that that there is a trend to use modern building materials unscrupulously killing the harmony and rhythm of the existing ancient structures. Ignorance and improper understanding of true Vāstu philosophy, the inbuilt sustainability aspects are left out while building new structures appending temple complexes when the whole world is advocating for Green buildings and Sustainable development.

The recent revivalism in Vāstu throughout India in last three decades has produced many 'experts' in different corners of the country. They refer to the traditional texts relevant in their region and follow those principles prevalent in their region. However, articles and papers published from different regions thus differ in many aspects and this has confused many practitioners in Kerala also with contradicting dictions, gathered from multiple sources. They seldom understand that Vāstu practice is region specific though the spirit and philosophy is Indian.

Another trend that has crept into Vāstu or rather in all traditional sciences is that people try to connect the principles with modern science without properly understanding both and glorify it without a proper rationale. The terminology 'Modern Vāstu' and its correlation with some 'energy fields' seem to be baseless and unscientific. Similarly, unfamiliarity of Sanskrit Technical literature also leads to misinterpretations. For example, 'Vimāna' means tall towers in Vāstu literature while in puranic texts it is an aero-plane. With reference to *Śilparatna*, while describing the use of the different Hastas, the Prājāpatya hasta of 25 Aṅgula is given as follows.

> yāne ca śayane kiṣku prājāpatyaṃ vimānake |
> ārā modyānakau tu prājāpatyakaraṃ śrutam ||

Literal Translation: *For vehicles, for cots etc. (furniture) Kiṣku shall be used, for tall towers prājāpatyam, for playgrounds and gardens (landscaping) too prājāpatyam is thought of.*

In some modern interpretations it could be read as 'aero-plane' instead of 'tall towers' which is incorrect.

Many Vāstu stipulations are conveniently forgotten or avoided as mentioned above, for instance no Vāstu expert advises to cut a tree after the rituals nor avoid trees as per Vāstu canons. The only exception would ′be the 'cutting of a tree' for the Dhvajastambha (Flag post) for temples, where rituals stipulated are somewhat carried out. So also in the case of cutting any Aśvattha tree (Arayāl) in any temple premises. Similarly, none of the Vāstu experts insist to plant trees as per Vāstu in the compound even if the extent of land can accommodate it. The real problem with Vāstu

Practitioners and the people who want a 'Vāstu compliant' home is that both do not fully believe in it to the extent that a house built fully adhering to the rules of Vāstu will meet all the requirements and needs . This is applicable not only to Vāstu, but also to all indigenous sciences like Ayurveda. In such a scenario sometimes unscientific mixing takes place or in many cases 'traditional elements' will be mixed for name sake, just for a flavor. . Even the 'Nalukettu' design which is adopted nowadays does not fully adhere to Vāstu rules though it is easy to incorporate them.

In an RCC building design that too in a small extent of land, the scope of Vāstu application becomes minimum. Another aspect of difficulty confronted by the Vāstu consultants is that their advice with respect to land development, foundation, basement etc. is never sought. This limits their area where they can make suggestions.

By and large, there is an impression that true Vāstu building means a lot many wooden carvings and fine works of Architectural appeals and hence it is not cost-effective. It is a fact that the Vāstu tradition used to camouflage structural elements with fine architectural finishes and these types of work have become the flag bearer of traditional architecture. However, from experience, it could be seen that conventional and traditional way of construction is most cost effective if its luxurious and sumptuous elements are dispensed with.

The world wide acclaim of Vastuvidya is through Maharishi Mahesh Yogi who promoted Vastuvidya in the name of 'Vedic Architecture'. He and his followers have a different perspective on Vāstu which is mainly holistic in nature and spiritual in its content. The exponents of Vedic Architecture are many in West. Currently they have institutions to teach and many project around the globe to spread the idea of Maharishi Vedic Architecture (MVA) and they firmly believe that the Vāstu is something superlative to the Green building initiatives and all. According to MVA *"The incremental, experimental basis for green building design is an inefficient way to achieve the full status of being a Natural Law-based architecture. While there is much that is valuable and important in the sustainable architecture movement, it needs an additional approach to help it to fulfill its goal of designing a building in complete harmony with Natural Law*".

Though such assimilation processes are taking place in the West, in India, currently the Vāstu tradition is not yet in the main stream and remains outside the formal education system as a mere remnant of a glorious past. It is between the two difficulties – over glorification on one side and total disparagement on the other side.

10.3 DEFICENCY AND PROBLEMS IN VĀSTU

The first and the foremost problem in Vastuvidya is that there are many texts on the subject matter which contains contradicting statements. These are written in a span of at least three thousand years and by authors hailing from different parts of Indian subcontinent. Extent of Indian culture in the remote past was from Russia in the West to Indonesia/Philippines in the East and Himalayas in the North to Sri Lanka in the South. This has created lot of confusion to its followers. . As stated earlier in the Chapter 4, the definition of Yojana, the length itself appears differently in different texts in different period.

As everything whether it is arts or science, in Indian culture is connected with Vedas, Vastuvidya which is considered to be Sthāpatya Veda has a religious and ritualistic outlook. As Vāstu tradition is very old and is a part of Vedas, it can be noticed that the rituals like *'Vāstubali'* is meant Vedic deities rather than the forms deities which are now worshiped based on *Āgama*, *Saṃhitās* and *Tantra*. The '*Vastupuruṣa-maṇḍala* 'and the assigned 'Padadevatas attest this. Moreover, Vāstu has its connection with the different Vedis (sacrificial altars) connected with Yajñas. And thus, Vāstu and rituals are inseparable as far as tradition is concerned. Moreover with the advancement of Astrology, the attributes of Yoni, Tithi, Nakṣatra, Āya, Vyaya, Vaya:etc. embedded in Vāstu were derived from one of the prime dimension, most commonly the perimeter of the room or house. This has also become another major aspect in Vāstu especially in its belief system. These two aspects now disconnect Vāstu from pure science and technology as modern sciences are working and expanding on a secular and rational platform.

As discussed in previous chapters there are many scientific thoughts and outstanding results produced in ancient India, however only results and findings are written down in texts. Moreover, there was a practice to hide knowledge even from the disciples. In a scientific world, the methodology, derivation and proof are equally or more important than the results. For traditional mathematics and astronomy, there are many texts or interpretations explaining the proof and derivations, Jyeṣṭhadeva (c.1530). However, in Vāstu, such proofs and derivations are not seen. Unlike the mathematical and astronomical interpretations, the vyākhyānas (interpretations) on Vāstu texts like Vimarsini of Śaṅkara (c,1475) on *Tantrasamuccaya* etc., are also mostly silent on the derivations or methodology of arriving the results, This prevents us from knowing the background, intents and purpose of each Vāstu canon and hence its scientific and rational basis can only be drawn hypothetically though some of them are clearly proven.

During the medieval period in India, the class structure in Hinduism was predominant. The influence of the same is seen in all Vāstu texts. Most texts in Vāstu connects different Vāstu classifications with Cāturvarṇya (Four classes of Brāhmaṇa, Kṣatriya, Vaiśya and Śūdra). Even the measuring scales are classified thus. From a modern perspective it is a clear discrimination and many criticize Vāstu traditions for such remarks and stipulations.

Another argument against Vāstu is that the specifications are applicable only to specific sizes and shapes and there no enough flexibility to extend the same to any desired shape or size. This was due to the unavailability of the design principles behind it and thus it affected or set a limitation to the creativity of Architects and Engineers. Moreover, Vāstu works on an ideal condition where as in modern engineering there are ways means to tackle the difficult situations with the help of science and technology. For example, in Vāstu it is required to discard a clayey plot, on the contrary in modern engineering practice, the building can be founded on piling even if the clay extends to a depth of 70-80*m*.

Another social aspect of Vāstu practice is that many Vāstu Pundits or Practitioners give hope or frighten the clients on the basis of certain Vāstu beliefs and try to exploit the common people.

As an overall assessment, dictions of Vāstu tradition are pragmatic in use and holistic in philosophy but at the same time dogmatic in approach and mystic in appearance. On analysis it could be seen that most of the Vāstu canons are developed based on the local climate and locally available building materials. In this context whether

Manuṣyālaya Candrikā which is written specifically for Kerala region, from Konkan region to Kanyakumari is applicable to wholly to West Bengal or Punjab is a question. Thus understanding the underlying philosophy for each area Vastu principles have to reoriented and redefined to suit local climate, local culture and other parameters governing the Vastu principles. This is the main reason for different and divergent views that are found in Vastu texts that have originating in different parts Indian subcontinent. This substantiate the need for a dynamic Vastu defined for each region.

CHAPTER 11

SUMMARY AND CONCLUSIONS

11.1 INTRODUCTION

In accordance with the objective of the present study the engineering aspects of the traditional architecture with special reference to Kerala region is carried out and the findings and conclusions are listed below.

11.2 SUMMARY OF STUDY

As a part of the study, the site selection and planning aspects in Vastuvidya are analyzed in detail. The site selection process *'Bhūparigraha'* is elaborate and Vāstu looks for a virgin, elegant, habitable land in an environmentally conducive atmosphere with abundance of flora and with soil having good bearing capacity and with underground water available at a reasonable depth. After the site selection, the process is *'Bhūparīkṣā'*. Many tests and procedures are recommended to ascertain the properties of soil and characteristics of ground. When these tests are analyzed it is seen that the procedures are mostly identical in approach and the forerunners of the current geotechnical investigation procedures. The notable difference is while the current practices were developed in the last two centuries mostly, the Vāstu procedures have been in vogue for a couple of millennia.

The principle of orientation and facing of the buildings and ground slope have prime importance Vāstu tradition always insists for placing the building in the true (cardinal or geographical) direction. In the present study the engineering need for such a guideline is substantiated from a planning and land use viewpoint.

Another stipulation made by tradition is that buildings must face East or North. With respect to the geographical position of India, especially Kerala in the Northern Hemisphere studying the climatology and sun diagram it can be scientifically seen that East and North facing will give more living comfort and reduce the heat load on buildings as well as the impact of the South –Westerly monsoon winds and heavy rain. Another criterion set in Vāstu that the preferable site slope shall be from South to North, or West to East or from South-West corner to North–East, This also can be mathematically proven that a slope towards the opposite directions to what is cited above will increase the heat radiation using the sun intensity calculation using the equation. $I_c = I_B.\cos\beta$. Moreover the slope will simultaneously help the storm water to flow away from front yard as facing is always East or North. Similarly, as wells are mostly located in North-East, the ground water replenishment and to some extent rain water harvesting will also take place naturally.

While Vāstu canons are depicted, the texts classify the recommendations as Uttama (Excellent), Madhyama (Good), Adhama (Satisfactory) and fourth category Varjjya (Not recommended or to be Rejected). Based on the present study, it is noticed that the 'Uttama' categories of recommendations in Vāstu guidelines are not arrived randomly but after a logical analysis of all favorable factors and consolidating and superimposing them eliminating all unfavorable factors. In terms of modern mathematics, this is preparation of truth tables and the same is called ‘Tautological Approach’, (Jose, and Rajasekhar 2018). As an outcome of this study, not only the underlying methodology is identified but also found that, changing one of these desirable attributes for any reason will affect at least one of the favorable conditions. That may be the reason why Vāstu stipulations are very often dogmatic.

As cited above in order to orient the buildings in the true geographical directions (which are different from magnetic directions), a method using the shadow of a gnomon is an age-old technique in India. It is known as *Diknirṇaya.* The present study makes a clear observation that an improvement in this method is suggested in *Manuṣyālaya Candrikā* (c.1530). This improvement is for a refinement of the result nullifying the effect of instantaneous declination (the apparent movement of the Sun in the North-South and South-North directions due to the effect of obliquity of Earth’s axis). The validity of the correction proposed in *Manuṣyālaya Candrikā* is proved mathematically as a part of this research study.

Prima facie many Vāstu stipulations appear to be very stringent and difficult to comply with. When these stipulations were studied closely, it is seen that many parallels are there between the modern practice and the Vāstu tradition, establishing the fact that Vāstu canons were *‘Building rules and Regulations’* of ancient times. When Kerala Building Rules (KBR) and National Building Code (NBC) are compared with the Vāstu tradition, amazing similarities in approach and setting various criteria are seen, irrespective of the fact that the Vāstu canons originated in antiquity.

The parallels between the Vāstu canons and contemporary Acts and Regulations that control the construction activities are incredible. The examples are many like, The Town and Country planning act (2016), The Kerala Conservation of Paddy and wetland Act, 2008, The Kerala Forests vesting and Management of ecologically fragile lands Act, 2003, Coastal Regulation Zone (CRZ) and regulating activities in the CRZ (1986), Kerala Panchayath Raj, Licensing of Livestock farms Rules, 2012 which are embedded in Vāstu canons also. In the locating the building footprint, tradition has shown an ingenuity by dividing the plot in to quadrants and again subdividing it into quadrants if size of quadrant is large till the required size of quadrant to accommodate the proposed building is reached. Certain quadrants are advised to be kept vacant also similar what is demarked for a landscape area or greenbelt. Moreover Vāstu insists to go for a rectangular or square division of plots maintaining the view that all irregular plots are inauspicious. This helps for planning and maximum utilization of plot area. On analysis it is found that this process and restriction on usage of certain quadrants will ensure full utility of the entire plot from a planning perspective and vacant quadrants will act as 'lungs' for the entire building cluster, when quadrants are occupied in future. This will also ensure ample airy atmosphere as vacant quadrants will act as path for wind flow as Vāstu cleverly have instructed to leave vacant quadrants in the prominent wind direction.

Similarly, Vāstu stipulations in deciding the room locations are also found to scientific depending on the direction of wind, solar radiation etc. Regarding proportioning rooms (length to breadth ratio) Vāstu stipulations and Golden ratio differs. Renaissance artistes and architects were very passionate about this ratio. In India the series from which the ratio is derived was known prior to Fibonacci, but this ratio has not gained any special attention. Modern text books attest that Vāstu recommended range is desirable from 'roominess' perspective (Arora, 2010).

The ideas regarding the Human Resource management, contained in ancient texts prove that in ancient India too HR management was a developed portfolio. ‘Skill set’ and ‘Job Description’ are two important itineraries in any modern organization set up. Vāstu texts are eloquent while dealing with the construction management and in defining the skill sets encompassing all vital aspects like technical, human and conceptual. The different attributes that a head of construction (Sthapati) should possess are given in all Vāstu texts enabling to select a good and suitable resource. The need for motivating workers for quality and productivity is a recent thought in management science, but in ancient India it was a part of tradition.

The need for employee incentive and the necessity of keeping them happy for ensuring quality and productivity was identified in Indian Vāstu tradition. This fact has not yet been brought to light with deserving attention. The section of classification of craftsmen concludes in *Mayamata* (300 BCE) with a verse reminding all that ‘*without those four categories of skilled work men, no construction work can be accomplished and hence they always deserve honorable treatment’*. All Vāstu texts have repeated this and *Manuṣyālaya Candrikā* (1550CE) has further elaborated it. The need for keeping “good work environment” and keeping workers “content and satisfied” has been categorically mentioned in *Manuṣyālayacandrikā*: ‘*for any design (concept) to convert it to a reality (to construct) workmen are inevitable and hence keeping all of them happy is all the more important and is the duty of the person who controls the endeavor’*. Giving gifts to all workers which is still practiced is a part of this tradition as it is explicitly mentioned that all concerned shall be properly honored with feasts and costly gifts, *Manuṣyālayacandrikā* (1530).

Regarding payment of wages, *Arthaśāstra* has mentioned that skilled labour like carpenter shall be paid 120 *Pana*s when the ordinary worker's wages was 60 *Paṇa*s. *Arthaśāstra* ensures proper payment of wages by imposing fine on non-payment of wage also. The evidence of popularity of Kauṭalya's *Arthaśāstra* in Kerala is attested by its translation of the same in Malayalam that too in prose (*Bhāṣākauṭalīyam* - probably the first prose in Malayalam literature) dating back to 12th Cent.

In the west, ideas of labour welfare in human resource management originated only in 1837CE, after abolishing slavery in 1833CE. In this context, the statements (referred to above) on labour welfare and labour motivation, thousands of years prior, deserves attention of modern management gurus and researchers.

Another unique aspect noticed from social perspective is that Sanskrit learning was popularized or made to the reach of all sections of society for the sake of Vastuvidya and other technical literature including Ayurveda. The aim was to give theoretical knowledge apart from practical training. In a period when Sanskrit learning was restricted to the so-called upper-class, the working class was given opportunity to learn Sanskrit to access Vāstu texts, which had much impact in later period from a social point of view, triggering demand for social justice and equality for the lower tier of community also. Theoretical training of workmen helped them to appreciate their task more as well as to deliver good quality of work. The renaissance that happened in Kerala due to the influence of *'bhakti movement'* had shaken the base of hierarchy based on caste, but slowly men of letters from any community gained respect from early 16th Century. *Ezhuthachan's* writing '*Rāmāyaṇam Kilipāṭṭu'* in Malayalam is a landmark in history, triggering a literary movement accessible to all, irrespective of the social tier. Study indicates that the Vāstu tradition also have played an important role in this social revolution.

The classification, selection, suitability, quality considerations and other allied aspects regarding construction materials are elaborately discussed in traditional texts. In a period where transportation of building materials was very difficult, local materials were insisted and used. This obviously would also go to make the constructions sustainable.

Abundance of timber in Kerala naturally went to make constructions here much timber-intensive in contrast with the neighboring Tamil Nadu where natural stones were abundantly used. Similarly, instead of stone masonry, use of laterite was very common in Kerala. Use of burnt as well as un-burnt bricks (adobe) was also not uncommon. Similarly, for roofing, apart from thatching with palm/coconut cadjans, by common people, tiles were prevalent. Copper plate roofing was adopted mainly for religious structures (Temples, Churches, Mosques, etc.) Lime was used for bonding material for masonry and plastering. Treatment of lime by adding herbal admixtures was practiced. Mud for brick making was also modified by adding admixtures of various types. Classification of timber based on its properties and treatment of timber were also done. Engineering classification of timber can also be seen recommending different species for different purposes. Engineered soil/clay (cob) was used for wall construction. Uses of iron /copper/ alloy nails have been specified.

On the detailed study on additives to various building materials the following observations are made which are relevant from engineering perspective.

In recent years many admixtures are there in the market as additives of cement and concrete. In Vastuvidya, it can be seen that the clay for brick manufacturing was also treated with herbal admixtures to get greater durability and strength. After doing chemical analysis of the herbs stated in texts equivalent or similar new polymer additives can be formulated and can be added to clay for quality improvement. Many accomplished contemporary architects are now advocating for mud walls. In this context also additives suggested in Vāstu texts can be experimented. Many conservation architects now specify the traditional admixtures. Hence more studies about these admixtures including its chemistry can yield useful results.

Five types of lime-cements (L-Cements) are specified. Each type is made with different admixtures of lime and fine sand in different proportions. The final product is called ‘kalka’ in Vāstu comparable with ‘clinker’ in modern cement industry. Each type of L-Cement was made by powdering the ‘kalka’ and used later. . When the ingredients are studied it is found that it is a mixture of argillaceous and calcareous materials with suitable herbal admixtures having cementing properties. Only difference when compared to the modern cement is that in this process no heating is done and the reaction is taking place at normal temperature at slow pace. Detailed study and chemical analysis can explore whether there is any possibility for developing a new ‘Green Cement’ based on the Vāstu specifications.

Structural Engineering in Vastuvidya has more or less been, so far, an unexplored area in the present study. Only a very few works have appeared on structural aspects of Vāstu. Columns or pillars, walls, wall plates, beams, rafters, ridges, traditional wooden trusses etc. constitute the main structural elements in the traditional architecture. The design and detailing of each structural elements are described in detail especially in Kerala texts. On studying the rules for fixing the lateral dimensional of a column (pillar), and other structural elements in Vāstu texts, it is pointed out in the present study that the most remarkable achievement is on the traditional column design rule depicted in *Manuṣyālaya Candrikā* (.1530) ahead of Euler (1744) on column buckling.

All ancient Vāstu texts including *Mayamata* (300BCE) had set the upper limit as 11 ensuring all columns are always short from structural Engineering point of view. *Manuṣyālaya Candrikā* (c.1530) went one step ahead in setting the lower limit also distinguishing a short column and pedestal which is amazing. The three aspects of column design are covered in a single verse in *Manuṣyālayacandrikā*.

1. There is a lower limit for L/D ratio that differentiates column and pedestal.
2. There is an upper limit for L/D ratio that differentiates a short column and long column.
3. In the case of tapered columns, the tapering ratio is also important to ensure an even stress distribution.

Manuṣyālaya Candrikā (c.1530) when **specifying lower limit as 4 and upper limit as 11 for slenderness of columns,** matching with the Indian code or any other code currently used worldwide, indicates that the author has fully conceptualised the structural behaviour of column, thinking much ahead of his times. Thus, setting a boundary between pedestal and column similar to that in modern Engineering theory is remarkable and pertinent as it signifies the proper understanding of the applied mechanics and structural engineering. Many other instances proving that in Vāstu, there prevailed proper understanding of the structural behaviour of different structural elements. This fact has been identified and elaborated in the present study.

In the absence of any pedagogical detail on the structural analysis, since only results are given in traditional texts the method of derivation of these results can only be hypothecated. Learning that prime criterion as the deflection in case of beam, some experiments might have been conducted on scaled models to fix the upper limit for deflection. The cause-effect theory (kārya-kāraṇa-siddhānta) was philosophically well established in India and considering the cause as 'load' and 'deflection' as effect, these rules might have been derived. Another technique which the tradition had been employing has been highlighted with due focus**: To limit the load, they have put restrictions on spans like, span of beam in longitudinal direction or in other words spacing of columns, shall not exceed the height of column etc.** For larger room spans in order to reduce the span of rafters, a truss (similar to queen post truss) were also envisaged which is called *Ārūḍḥottaram* arrangement (Jose and Rajasekhar, 2018).

Among the special structures, theatre structures described by Bharata (300BCE) are studied in detail. Nāṭyagṛhas are theatre structures. The first opera house open to the public was built only in 1637 (Teatro San Cassiano) in Venice. This was the model for the subsequent theatres throughout Europe. The design details of the classical theaters that evolved during after 17th century are described in the Architect's Data (2012).

Going through *Nāṭyaśāstra* written by Bharata (300BCE), it is astonishing that almost the same numbers have been mentioned clearly for fixing the size of auditorium and stage which makes us to believe that it is not just a coincidence, but as an outcome of scientific thought and rational thinking. Thus rectangular theatre in *Nāṭyaśāstra* is perfectly matching with classical theatre design rules. On detailed analysis it could be seen that, for ease of computation *Nāṭyaśāstra* has taken α ~28 degrees instead of α =30 degrees in Architect's Guide, slightly smaller value so that $\tan\alpha$ =0.25. Here it is pertinent to note that the similarities in the results make us presume that the concept of *'vision triangle'* was known to the author of *Nāṭyaśāstra*.

The three shapes recommended for nāṭyagṛha (theatre structure) are Rectangle, Square and Triangle, with options of size. Of these Bharata suggests to adopt medium size from audio-visual considerations. The awareness of acoustics including the distance of echo formation and its causes, reverberation etc., are evident from the text. Unlike the usual buildings Bharata recommendations to place doors and windows staggered deserves special attention and could be adopted in modern context too, to minimize echo (Rajasekhar, 2000).

Though *Nāṭyaśāstra* has mentioned a triangular Theatre as a possibility and only minor details are mentioned, further geometry and details are not given as in the case of rectangular and square Theatre. Hence no reference regarding triangular theatres is available now in the literature. From the finding that *Nāṭyaśāstra* has also derived the geometry from the vision triangle with 28 degrees, the puzzle of triangular Theatre is resolved in the present study.

Without the support of the any developed geotechnical engineering practice as we have now, it is a mystery or a wonder , that many tall *Gopura*s (Gate Towers) and *Vimāna*s (main structure) having a height in the range of 30 m to 70 m standing the test of time without any settlement or distress for the past thousands years in South India.

Soil Mechanics is one of the recent branches in Civil Engineering starting with '*Theoretical Soil Mechanics*' (Karl Terzaghi, 1943), but principles of geotechnical engineering was not unknown to India All Vāstu texts have a chapter on *'Bhūparīkṣā'* meaning testing site (soil). In site selection processes, some engineering properties of soil were also analyzed and investigated though in a rudimentary form which could be seen as anticipations of several modern theories and methods in the Geotechnical engineering procedures and investigation.

With reference to IS 1892-1979: Indian Standard code of Practice for subsurface Investigation for Foundation, the parallels between traditional approach in site reconnaissance and site investigation and current practices could be recognized easily.

A forerunner of "Acoustic Characterization of Soils" under seismic method of testing is also mentioned in Vāstu tests. Tests resembling Standard Penetration Test (SPT) can also be seen in Vāstu depictions. Another test is reading field penetration test. Among properties of soil bulk density is also included. This desirable property is called *'bahupāṃsu'* in Vāstu terminology is a measure or indication of field compaction of in-situ soil. Soil classification also is seen to have been mentioned.

An interesting general observation on traditional buildings are that they are foundation ***less structures*** from a modern perspective The system of excavation up to ground water level (GWL) or minimum 2.2 m (Puruṣāñjali) or up to rock and then improving the ground with well-graded engineered backfill material to ensure proper compaction was the accepted procedure.

While fixing the finished ground level, there was a system of raising the proposed ground level. Raising the ground level was also done by ‘well graded’ soil as specified above. This will ensure proper drainage from the central courtyard and raised platform will prevent the ingress of dampness.

Basement-height of common residences are one Hasta or 72 cm. This was the height previously adopted in Kerala. This had a definite advantage especially in flood prone areas in giving sufficient warning regarding inundation of houses. The traditional system of raising the site by 36 cm and then providing a clear basement height of 72 cm was very much advantageous in Kerala where rainfall is heavy and most of the residential areas are in the flood plains of rivers.

The basement traditionally was decorated with a moulding (usually sculptured for temples etc. from rock itself as an integral part) popularly known as ‘*pañcavarga’* which was a unique outstanding feature of our traditional buildings. This was mandatory for temples in ancient times. This not only added to the beauty of the basement but also acted as a reptile trap owing to its unique design.

The studies on this aspect in the Cochin University of Science and Technology under the title ‘Effect of Stage Loading on Cochin Marine clay’ has proved that certain nāṭṭarivu (indigenous knowledge) regarding ‘**stage-wise loading of foundations helps to reduce settlement’** has scientific validity (Rajasekhar, 1991).

Kerala witnessed an unprecedented advancement in Mathematics during 1300-1700 and further sustained its glory up to 1850. Kerala mathematics could transcend from finite systems of Mathematics to infinite analysis (Joseph, 2000). Saṅgamagrāma

Mādhava (c.1340-c.1425) could formulate the series expansions for π, $\cos\theta$, $\sin\theta$, $\tan^{-1}$ etc. centuries before Gregory (1638-1675), Newton (1642-1727), Leibnitz (1646-1716)., Wallis (1616-1703) etc., and this is duly acknowledged by European scholars like John Warren in early 19th century itself (Wish, 1835). The scholars following the school of thought of Mādhava made several breakthroughs in Mathematics and Astronomy from 14th to 18th Cent and their contributions are studied now under the legend 'Kerala School of Mathematics'. As an outcome of this study it has been identified that Kerala Vāstu tradition which was developed in the medieval period has a connection with the mathematics school and has developed under its influence, (Rajasekhar, 2018).

From the study it is established that influence Kerala School Mathematics has been instrumental in evolving a new stream in Vastuvidya with *Tantrasamuccaya* (c.1460), which could be termed as 'Kerala school of Vastuvidya' and further Kerala has made some remarkable achievements and contributions in Vastuvidya too.

Coming to sustainable development, philosophically Vāstu tradition and Green initiates have cohesions. Vāstu canons have always been giving due consideration for environment. Due care was taken to see that the ecology and maintenance of bio-diversity is not at all disturbed. In listing the undesirable tress or trees not to be cut, its concern about the nature has been expressed explicitly. "*Tress that are depended by birds and animals; Trees embraced by creepers; Trees that blossom and bears fruit in odd seasons.*' These three canons suffice to prove its commitment to environment and awareness of biodiversity and awareness of protecting the need of rare species. There is a real scope for the amalgamation of Vastuvidya and Green initiatives and to have better pragmatic design concept.

The main drawback of the current Vāstu practice is that it mainly gives emphasis to the belief system connected with Vāstu and tries to maintain its mystic halo which might have restricted its acceptance among the engineering community. However there is a need for a ‘dynamic Vāstu’ system rather than the present inflexible and static Vāstu. A dynamic Vāstu has to be formulated which can be globally, applicable in all countries and all climate zones.

The scientific and rational elements in Vāstu were very often ignored or marginalized for varied reasons and even today Vāstu remains alien to the scientific community. From the above study, it is evident that the ‘Engineering Aspects’ that are dealt in Vāstu are worth studying both from an engineering point of view and from an indigenous epistemological perspective. A close perusal of Indian scientific literature shows the fact that the Indian scientists had also maintained a high scientific temperament far ahead of others. Their dictions were based on rationale *(yukti)* and not based on any scripture or mythology *(purāṇa*) as explicitly stated by Nīlakaṇṭha (1444-1544CE): ‘*ityetat sarvam yuktimūlameva, na tvāgamamūlam’* (all *these (proofs) are based on rationale not based on any (puranic) scripture)* (Sundareswaran, 2014.).

11.3 FINDINGS

The present study is confined to secular and scientific aspects in Vāstu only. The aspects connected with ‘belief systems’ are not considered under the purview of this study. The study has attempted to figure out certain design philosophies and principles also apart from the analyzing and comparing Vāstu with modern science and engineering. Certain social and historical points are also included. The conclusions and findings in the present study are summarised below:

1. Vāstu rules regarding site selection, planning etc. have scientific basis and parallels between many building regulations can be seen.

2. While setting 'Rules' Vāstu has followed a tautological approach.

3. Structural design and concepts in tradition reveals that structural engineering concepts were not alien to Vāstu. Some depictions are proved mathematically as a part of this study.

4. The mentioning of upper limit and lower limit regarding slenderness of columns in *Manuṣyālaya Candrikā* (c.1550) much ahead of Euler (c.1744) is amazing.

5. As a part of the study, it was found that all tall gate towers and temple structures in the range of 70m are only located in the Zone-II –Earthquake zoning and moreover all texts restrict height to 72m giving no chance to dynamic effects.

6. Many geotechnical tests and soil investigation procedures and classification are seen to have mentioned establishing that 'soil mechanics' had also a humble beginning in India far ahead of modern seats of learning.

7. Regarding Foundation construction, Vāstu tradition has clear understanding about bearing capacity and need for ground improvement and in formulating specifications for *in-situ* compaction.

8. As a part of study, a new formula is derived for in-situ permeability coefficient evaluation.

9. Human Resource Management aspects that has been mentioned in Vāstu, centuries or millennia before the present day theories and labour laws is also studied from a contemporary scenario.

10. Design and construction of 'Nāṭyagṛhas' detailed in *Nāṭyaśāstra* is studied in details high lighting its special features from visual and acoustic perspective as mentioned in the text.

11. As a part of the study, the puzzle regarding the 'Triangular Theatre' is resolved and presented.

12. The influence of Kerala medieval mathematics which is more recognised elsewhere than within the country, on Vāstu is identified in the present study.

13. Environment aspects and sustainability concepts are studied. Possibilities of making new ‘Green products’ based on Vāstu specifications are mentioned.

14. Problems and issues in current Vāstu practice are brought out and need for a ‘Dynamic Vāstu’ concept proposed.

11.4 CONCLUSION

Considering the vastness and depth of the subject, only a small portion of the Vāstu tradition is only covered in the study. The scope for further studies is considerable. The impression of an occult science keeps away the engineering faculty from this ancient wisdom. This shadow should not deter any researcher to separate out the scientific aspects from Vāstu lest we will not be able do justice to our history.

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