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KNOWLEDGE OF ASTRONOMY IN SANSKRIT TEXTS OF ARCHITECTURE (ORIENTATION METHODS IN THE *ĪŚĀNAŚIVAGURUDEVAPADDHATI*[1])

Determination of the cardinal directions was one of the prerequisites for constructing sacrificial altars and for building houses and temples in ancient India. In Sanskrit texts of the *śulbasūtras, śilpa-* or *vāstu- śāstras*, and *āgamas*, mentions are made to various methods of orientation which show different levels of knowledge of astronomy (*jyotiḥśāstra*). The orientation methods are roughly divided into two categories: the observation of fixed stars and the observation of gnomon shadows. The former is subdivided into *nakṣatravedha*[2] (observation of the lunar mansions on the eastern horizon) and *dhruvavedha*[3] (observation of the polestar). The latter, the method of using gnomon shadows, was first described in the *Kātyāyanaśulbasūtra*, and later it found a significant development after the introduction of the Hellenistic astronomy into India, where the gnomon was extensively used in the stereographic projection known as analemma[4] in Greek astronomy. Some authors of the *vāstuśāstras* and the manuals of temple architecture who were not indifferent to the new progress of astronomy tried to incorporate new rules into their texts, sometimes without understanding the context. In what follows I would like to give an illustration of the inter-śāstra relation between astronomy and architecture concerning the orientation methods, with special reference to those which are recorded in the *Īśānaśivagurudevapaddhati*, which is an encyclopedic manual of Śaivasiddhānta written, probably, in the late eleventh or early twelfth century. Our topic is found in the *Śaṅkucchāyādhikāra* of the 24th *paṭala* of the *Kriyāpāda*, which presents the variety of orientation methods in the more learned way than the texts of architecture proper.

1. METHOD OF THE SO-CALLED INDIAN CIRCLE (FIGURE 1)

After giving introductory remarks about the auspicious days for setting up the gnomon, preparation of the ground, and selection of the material for the gnomon (verses 1 to 4), Gurudeva, the author of our text, draws a circle around the foot of the gnomon. The radius of the circle is equal to the length of the gnomon[5] (6). "When in the forenoon", he says, "the head of the gnomon-shadow enters the line of (the circumference of) the circle because of the decrease (of the shadow length), one should mark the tip of the shadow. In the afternoon likewise mark (the tip of) the shadow which is going out of the circle touching the line (of the

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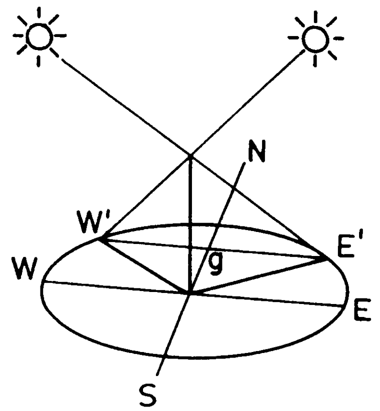

Figure 1.

circumference) as before. One should draw a straight line (connecting) the two points (marked) in the forenoon and afternoon. They are the east and west directions." (7–10)[6]

This method, which is good enough for practical purposes, must have been used most commonly throughout the history. No text on architecture discusses the orientation problem without mentioning this one. The earliest reference to the method, as far as I know, is found in the *Kātyāyanaśulbasūtra* 2, which runs:

same śaṅkuṃ nikhāya śaṅkusammitayā rajjvā maṇḍalaṃ parilikhya yatra rekhayoḥ śaṅkvagracchāyā nipatati tatra śaṅkū nihanti sā prācī |

"Driving the gnomon into the levelled (ground), and drawing a circle with the rope whose length is equal to the gnomon (length), one drives two pegs at (the intersections of) the two lines where the shadow of the tip of the gnomon falls. This is the east (-west) line."

The circle thus drawn in this method, as well as the method itself, is called 'Indian Circle' by al-Bīrūnī in his extensive treatise on shadows[7]. However, this simplest and most standard method, says Gurudeva, is regarded by some people as one that is applied to the place of zero-latitude (*nirakṣadeśa*) like Laṅkā. Without adding any comment to it, Gurudeva proceeds to the next rule which, 'according to others' (*anyaiḥ*), is applicable to the *sākṣadeśa*, i.e. the place having latitude. In fact, there is no reason for differentiating the *nirakṣadeśa* and the *sākṣadeśa* as far as the orientation method is concerned. Moreover, no place in the Indian subcontinent is located on the zero-latitude, nor even in the island of Śrī Laṅkā, whose southernmost latitude is about 5° N. In the astronomical texts, however, such theoretical reference to the *nirakṣadeśa* or Laṅkā is quite common.

2. CORRECTED INDIAN CIRCLE METHOD (FIGURE 2)

Gurudeva quotes two verses which prescribe a rule for the correction of the simple

Indian circle method, though he regards it as the rule for the sākṣadeśa. The verses, which he ascribes to 'others', and which were not identified by the editor of the published text, are nothing but Śrīpati (1039/56)'s *Siddhāntaśekhara*, Chapter IV, verses 2 and 3:

yāti bhānur apamaṇḍalavṛttād dakṣiṇottaradiśor anuvelam/
tena sā dig anṛjuḥ pratibhāti syād ṛjuḥ punar apakramamaurvyā//
chāyānirgamanapraveśasamayārkakrāntijīvāntaram
kṣuṇṇaṃ svaśravaṇena lambakahṛtaṃ syād aṅgulādyaṃ phalam/
paścād bindum anena ravyayanataḥ saṃcālayed vyatyayāt
spaṣṭā prācyaparāthavāyanavaśāt prāgbindum utsārayet//

"Since the sun moves to the south or north (of the equator) along the ecliptic every monent, the direction (thus found) is not correct. The correction on the other hand is to be made by means of the Sine of the (sun's) declination.

The difference of the Sine of the sun's declination at the time of shadow's entry into and exit from (the circle) is multiplied by its (i.e. shadow's) hypothenuse and divided by (the Sine of) the terrestrial colatitude. The result is digits (*aṅgulas*) and so on (of the correction). One should move the western dot by this amount to the direction opposite to sun's course (*ayana*), or one should move the eastern dot to the direction of the sun's course. (Then) the true east-west line (is obtained)."

This rule can be expressed by modern formula:

$$\Delta s' = \frac{h(\text{Sin}\,\delta_1 \sim \text{Sin}\,\delta_2)}{\text{Sin}\,\bar{\varphi}}\,, \tag{1}$$

where h is the hypothenuse of the shadow, δ_1 and δ_2 are the declination of the sun at the two moments, and $\bar{\varphi}$ is the terrestrial colatitude[8]. That the rule is mathematically correct can be easily demonstrated if one knows the formula for finding the distance of the tip of the gnomon-shadow from the east-west line (s' in Figure 2), as is given, for example, in the *Pañcasiddhāntikā* IV, 52–54 or *Brāhmasphuṭasiddhānta* III, 4, namely,

$$s' = s_0 \pm \text{Sin}\,\eta \times \frac{h}{R}\,, \tag{2}$$

where s_0 is the equinoxial noon shadow, R is the radius of the great circle, and Sin η is the Sine of sun's rising amplitude which is obtained by

$$\text{Sin}\,\eta = \frac{R\,\text{Sin}\,\delta}{\text{Sin}\,\bar{\varphi}}\,. \tag{3}$$

Probably it was Brahmagupta (b. 598) who made the first recorded claim that the simple and practical method of orientation was theoretically not accurate

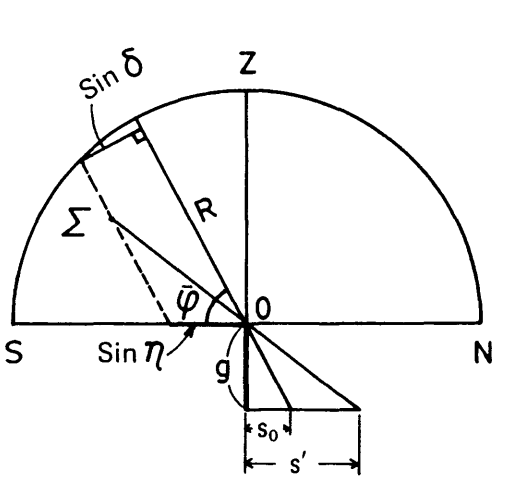

Fig. 2a

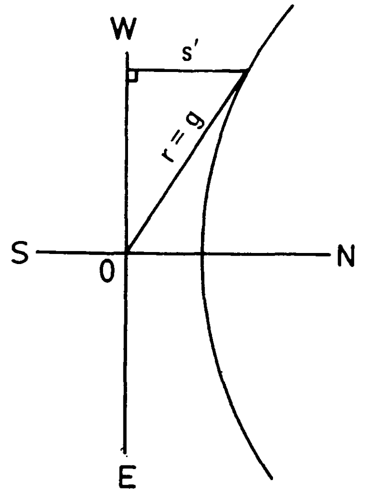

Fig. 2b

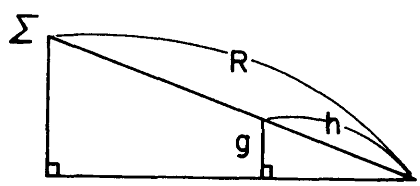

Fig. 2c

because the change of the solar declination was not taken into account. His words, however, are not clear, nor did he give any formula for the correction. He only says:

"At the two tips of the equal shadows (when the sun is) in the eastern and western (hemisphere), two dots (are marked). The first one is the western direction and the second one is the eastern, depending on the (solar) declination. From the mid-point of the (two) to the foot of the gnomon are the other two (i.e. the northern and southern directions). (BSS III, 1).

One might well say that the true correction method was within easy reach of Brahmagupta whose formula referred to above (2 on p. 19) was only one step to the correction formula, and in fact, Pṛthūdakasvāmin's commentary (864) on this verse (BSS III, 1) is based on the same assumption. But Brahmagupta's own word, *krāntivaśāt* ('depending on the declination'), is too brief a statement to ascribe to him the priority for the correction formula[9]. Pṛthūdakasvāmin evidently knew the formula, but unfortunately he failed in its versification. Even if an Indian scientist in the classical age discovered a new theory, his claim for priority could not be accepted unless he versified the formula in Sanskrit.

It was significant, therefore, that Śrīpati was for the first time successful in versifying the formula for the correction to the simple Indian circle method of orientation. After Śrīpati the formula became a common knowledge of Indian astronomers and many authors beginning with Bhāskara II (b. 1114) versified the rule in their own way[10]. The fact that Śrīpati's verses were quoted by Gurudeva goes quite well with the fact that one of the authors who were most frequently referred to by him was Bhojarāja, the author of the *Samarāṅgaṇasūtradhāra* who was contemporary with Śrīpati. The upper limit of Gurudeva's life, therefore, is the mid-eleventh century.

The reader of Gurudeva's brief commentary on the quoted verse might have an impression that he had a good knowledge of astronomy. But it is possible that the commentary itself is a quotation from some astronomical texts, as is definitely the case with the other instance that will be explained below.

3. THREE-SHADOW METHOD (FIGURE 3)

Immediately after describing the orientation method of the corrected Indian circle, Gurudeva speaks of another method which can be carried out 'even without sun ('s declination) and the terrestrial latitude'. The verse is numbered as 15 in the Trivandrum edition as if it were Gurudeva's own, but, in fact, it is another quotation from the *Siddhāntaśekhara*. The verse is quoted in a corrupt form. I follow Śrīpati's words in my translation except reading *śaṅkudiśā* instead of *śaṅkudiśoḥ*:

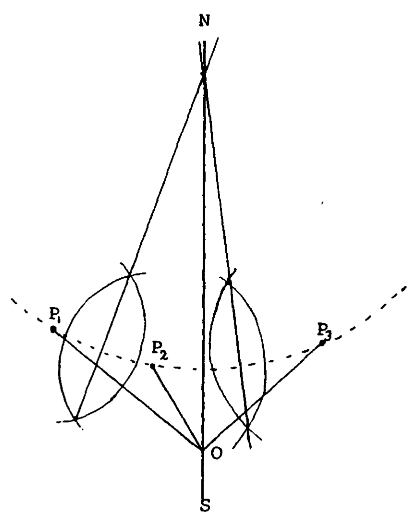

Fig. 3.

chāyātrayāgrodbhavamatsyayugmasp̣rksūtrayor yatra yutiḥ pradeśe/
yāmyottarā śaṅkudiśoḥ kakup sā krameṇa saumyetaragolayoḥ syāt//

"At the place where there is an intersection of the two lines passing through the two fish (-figures) which are produced from the tips of three shadows, (a line is drawn toward the foot of the gnomon). The direction of the gnomon is the south or north direction according as (the sun is) in the southern or northern hemisphere, respectively."

Gurudeva begins the commentary with a correct paraphrase of the text, then he adds a very detailed and useful explanation pretending as if it were his own. But, to our interest, the main part of the explanation is nothing but a word to word copy of Pṛthūdakasvāmin's commentary[11] on the *Brāhmasphuṭasiddhānta* III, 2!

The three shadow method, to which the oldest reference is found in the *Pañcasiddhāntikā* XIV, 14–16, is mathematically not correct, since the line drawn by the tip of the gnomon shadow is not a circular arc but a hyperbola, as al-Bīrūnī correctly observed in his criticism to Brahmagupta's three shadow method[12]. The approximation, however, does not produce a gross error near the vertex of the curve, i.e. near the noon-shadow.

4. APACCHĀYĀ TABLE (FIGURE 4)

The last part of Gurudeva's discussion on the orientation is assigned for a subject called *apacchāyā*. Before defining this strange word let us have a look at the table of the *apacchāyā* given by him. After a slight emendation, the three verses (18–20)[13] can be tabulated as below:

Table of apacchāyā

'days' / signs	0–10	10–20	20–30
Aries	2	1	0
Taurus	0	1	2
Gemini	2	3	4
Cancer	4	3	2
Leo	2	1	0
Virgo	0	1	2
Libra	2	3	4
Scorpio	4	5	6
Sagittarius	6	7	8
Capricorn	8	7	6
Aquarius	6	5	4
Pisces	4	3	2

Since thirty-six decades cover one complete solar year, the 'days' here mean solar (*saura*) days. Values for Taurus 10–20 to Leo 10–20 are negative ones, namely,

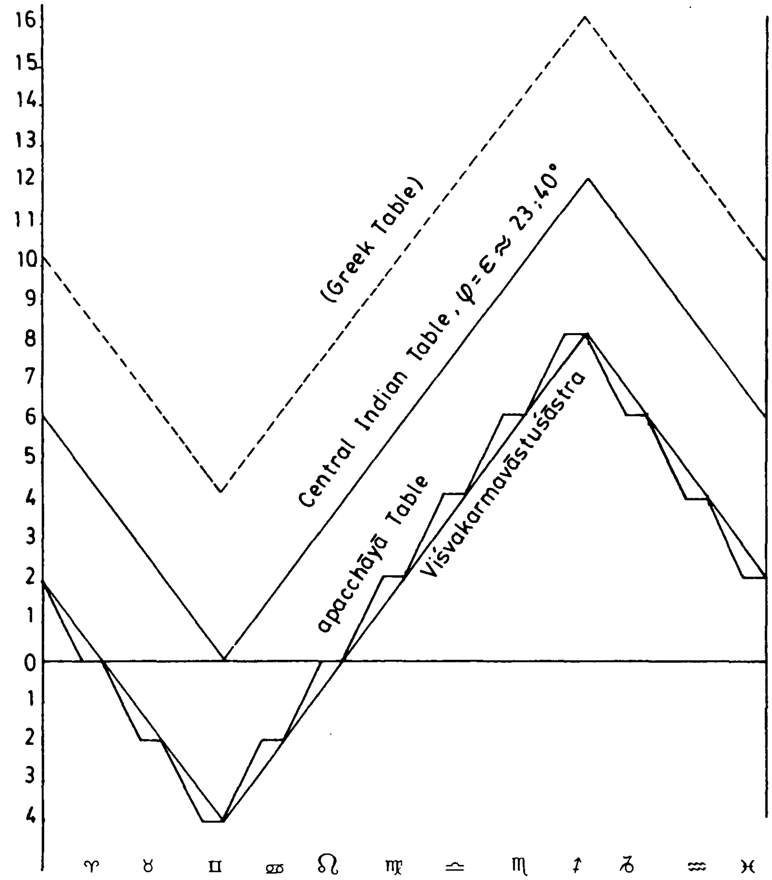

Fig. 4.

shadows cast to the south. Exactly the same table is given in the *Mānasāra* VI, 2 to 38 as well as in the *Mayamata* VI, 11 to 13 and 27, both in the context of orientation. This table was one of the most vexing factors to P. K. Acharya when he wrote a paper on 'Determination of Cardinal Points by Means of a Gnomon' (1928), where his main point of discussion concerned the orientation methods in the *Mānasāra*. He tried to interpret the table of *apacchāyā* in the context of the rectification of the simple Indian circle method, and suggested that the numbers in the table represented some elements of correction. But he could not convince even himself, because he knew that "the time when the correction is zero should be the solstices, but it is not so in the *Mānasāra*[14]." So he had to admit his inability and welcomed suggestions for solution saying, "If no proper solution be found, there is a danger of these ancient authorities being held as erroneous and misleading." The same view was held in his translation of the *Mānasāra* (1934), and in his *Encyclopedia of Hindu Architecture* (1946)[15].

A clue to the solution was offered by the late Prof. J. Filliozat (1952) who thought that the numbers of the table had nothing to do with the correction, but they simply represented the noon shadows of the 12 aṅgula gnomon[16]. His interpretation was essentially right, but he proceeded to a wrong direction and labored with the *apacchāyā* table in order to determine the geographical latitude of the place where the *Mānasāra* was supposedly composed. He got three results 10°, 9°, or 5° North from the shadows at the winter solstice, equinoxes, or the summer solstice, respectively. In a supplementary remark, he added another value 7; 50° computed by M. Tardi and, it seems, he could not deny the possibility of Ceylon as the provenance of the table.

Dr. Bruno Dagens was also annoyed by the *apacchāyā* table when he translated the *Mayamata* (1970). He first interpreted the numbers of the table as the values to be corrected because they were used with the verb *śuddhyate*[17]. The numbers, according to him, stood for the distance ($\acute{s}$ in Fig. 2 and formula 2) from the tip of the shadow to the east-west line. Taking the context into consideration, his interpretation does not seem utterly impossible, but in the 'ERRATA AU I° VOLUME' appended to the second volume he abandoned his hypothesis and followed Filliozat's suggestion. I computed $\acute{s}$ with $g = r = 12$ for $\varphi = 10°$ N and compared the results with the noon shadows (Figure 5). It is clear that the *apacchāyā* numbers are closer to the noon shadows than to $\acute{s}$'s.

Now I would like to offer a new solution to the problem from the different angle. Even though the modes of versification are different, the *apacchāyā* tables in the *Mānasāra, Mayamata*, and *Īśānaśivagurudevapaddhati* represent the same thing: variation of the length of the noon-shadows expressed in a modified linear zigzag function. Prof. O. Neugebauer would classify it in his Type Z, namely, the type of the shadow table where the variation of shadow length is expressed as the function of the solar position in the zodiacal signs[18]. In fact, there exists a simpler shadow table of the same type in the *Viśvakarmavāstuśāstra*[19], another text of architecture. The text reproduced by D. N. Shukla is very corrupt, but the several correct numbers allow us to safely restore the original table. The result is a very simple linear zigzag function of which maximum is 8 aṅgulas at Capricorn and minimum is -4 (minus values indicate the noon shadow cast to the south) at Cancer, the interval of entry being a sign.

This simple scheme immediately reminds us of the shadow tables of the central India, one of the oldest of which is preserved in the *Arthaśāstra* II, 20, 39–42, where noon shadows are tabulated as the function of solar month. The maximum length is 12 aṅgulas in the solar month Kārttikā (when the sun is in Capricorn)

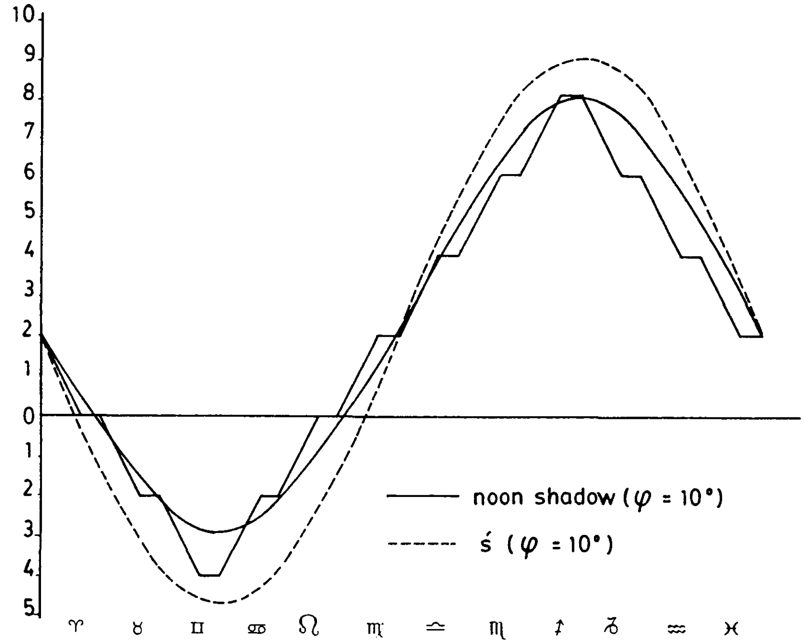

Fig. 5.

and minimum is 0 in Aṣāḍha (the sun in Cancer). The amplitude (i.e. the difference between maximum and minimum) of the function is 12 just as in the case of the *apacchāyā* table. Based on the same simple zigzag function is Vasiṣṭha's rule for obtaining the length of the noon shadow (*Pañcasiddhāntikā* II, 9–10). Prof. David Pingree has shown[20] that another table for the variation of shadow-length during the day was given in the *Arthaśāstra* and, with a slight modification, in the *Śārdūlakarṇāvadāna*[21] and that their fundamental scheme was very similar to that of *mul Apin*, a Babylonian series compiled in about 700 B.C. It is highly probable that a set of the Babylonian shadow tables was transmitted to India and thereafter handed down to the south undergoing the simple modification (parallel displacement, to use mathematical terms) in order to accomodate itself to the south Indian latitude without changing the fundamental scheme of the linear zigzag function. By a further manipulation a month was divided into three decades while the monthly increment of 2 aṅgulas was maintained, and the result was the peculiar table. Finally some architects like the author of the *Mānasāra* who were ignorant of astronomy blindly incorporated the *apacchāyā* table in the context of the correction for the orientation method.

The fact that even P. K. Acharya, one of the most learned historians of Indian architecture, was not familiar with jyotiḥśāstra is well demonstrated by his wrong reference to astronomical texts: he did not know that in the texts of jyotiṣa the problem of gnomon shadow concerning orientation was *not* the subject of the Śaṅkucchāyādhyāya but that of the Tripraśnādhyāya. His ignorance was such that he even dared to say, "for the purpose of rectifying the inevitable variation of the shadow no specific rules appear to have been laid down in any of the numerous astronomical and architectural treatises except in the *Mānasāra* and *Mayamata*." [22] Compared with the modern Acharya or the ancient authors of the *Mānasāra* and *Mayamata*, Gurudeva was better informed of astronomical texts, but still he could not properly handle the information he got.

Lastly I want to refer to Neugebauer's works on the primitive shadow tables[23]. He has collected dozens of Greek shadow tables and their derivatives and variations in Coptic, Ethiopic, Arabic, Syriac, Armenian, and Latin literature. Of particular interest among them is one ascribed to 'Philip, the King of the Greeks', in which maximum length is 8, minimum 2 for $g = 6$. When all the numbers are doubled, the table would turn out to be a possible candidate for the prototype of the Indian tables, with the normative amplitude 12. According to Neugebauer, the Greek scheme is unrelated to *mul Apin*'s approach[24]. Then how to interprete the survival in India of the two types of shadow tables: the *mul Apin* type giving the variation during the day, and the Greek type of the annual variation? In any case what Neugebauer said concerning the shadow-tables he examined is beautifully applicable to the Indian tables: "Ironically, the primitive, geographically inflexible method survived all scientific progress, being handed down deep into the late Middle Ages."[25]

We have seen how a very elaborate method of orientation and the far primitive table of shadows were coexistent in the same text of temple architecture. This is not the unique case in the history of Indian science where conservatism played a significant role. Everything handed down was preserved, including those things which had no practical use and whose meaning was no more understood. It is thanks to such Indian attitude, however, that modern historian can hope to find fossilized elements of the remote past.

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NOTES

[1] I thank Prof. Yasuke Ikari of Kyoto University who stimulated my interest in this text and who kindly provided me with bibliographical information on āgamas.

[2] *Mānavaśulbasūtra* X, 1, 1, 3: "When a pair (of the following lunar mansions) has risen the measure of a yuga (yoke, 86 aṅgulas) (above the horizen): citrā and svāti, śravaṇa and pratiśravaṇa, kṛttikā and pratikṛttikā, tiṣya and punarvasu, between (such a pair) the eastern quarter is found, (brought into line) with the ties (of the cord). (Tr. by J. M. von Gelder). Similar idea is found in Dvārakanātha's commentary on *Baudhāyanaśulbasūtra* 22, and Karka's commentary on *Kāstyāyanaśulbasūtra* 2, *Aparājitapṛcchā* LXIII, 21, 22, *Kāmikāgama* XV, 33, *Mṛgendrāgama* VII, 7.

[3] References to this method are found only in such later texts as *Aparājitapṛcchā* LXIII, 30, *Kāmikāgama* loc. cit., and *Mṛgendrāgama* loc. cit. It seems that there was no bright star near the north pole in the days of the *śulbasūtras.*

[4] Neugebauer *ESA*, p. 214–215, *HAMA* V.B. 2, Pingree (1978), p. 547 and passim.

[5] The standard length of the gnomon is 12 aṅgulas, but references to the 18 or 24 aṅgula gnomon are not rare. There is no compelling reason for the radius of the circle to be equal to the gnomon-length, except for the convenience for computation of the hypothenuse of the shadow $\sqrt{2}$g.

[6] *bhramayet paritas tena bindau sthitvā suvartulam/*
tanmadhyabindau taṃ śaṅkuṃ sthāpayed udaye raveḥ//
tadbimbavṛttarekhāyāṃ śaṅkucchāyāśiro yadā/
hrāsād vi[ṃ]śati pūrvāhṇe tatra cchāyāgram aṅkayet//
tathāparāhṇe cchāyāyāṃ nirgacchantyāṃ tu maṇḍalāt/
saṃspṛśantyāṃ tu tadrekhāṃ prāgvat tatrāpi lāñcayet//

[7] *Risā'il* p. 108f, tr. p. 151f.

[8] I follow Neugebauer's notation for Indian Sine, e.g. Sinα for Rsinα.

[9] Besides Śrīpati's formula there are several attempts for correction. Govindasvāmin (ad *Mahābhāskarīya* III, 2) draws three concentric circles around the foot of the gnomon, thus observations are made three times each in the forenoon and afternoon, *Ajitāgama* IX, 8 refers to the same method. *Manuṣyālayacandrikā* II, 3–4 offers an interesting method. Observation is made in two successive days at the same hour in the morning. A third of the difference of the shadow-lengths is applied to the afternoon shadow of the first day. This method is quoted in Ravi Varma's modern commentary on *Vāstuvidyā* p. 29f. The same method is found in the *Śilparatna* (XI, 2). In Āmarāja's correction (ad. *Khaṇḍakhādyaka* p. 86) $\Delta t/60$ is used instead of $\frac{1}{3}$ days, which reminds me of al-Bīrūnī's report on Puliśa's correction (*Risā'il* p. 114). *Mānasāra* VI, 15 gives a terrible 'correction' $\frac{1}{96} \times$ g.

[10] Among others, *Śilparatna* XI, 9–12. *Śilparatna* XI, 3 to 5 are from *Siddhāntaśekhara* IV, 1 to 3. *Vāstuvidyā* III, 9 & 10 are *Siddhāntaśekhara* IV, 2 & 3.

[11] I thank Mr. T. Kusuba who sent me copies of the manuscripts Pingree 15 and 16 which were copied from VVRI 1781 and BORI 339, respectively. Also thanks are due to Mr. Y. Ohashi who sent me a copy of VVRI 1781.

[12] *Risā'il* p. 115, tr. p. 161, comm. p. 91.

[13] *dvayam ekaṃ na naikaṃ dve netrāgniśrutisaṃkhyayā//*
vedāgnidvayamānena dvayam ekaṃ na kiṃcana/

naikanetrābdhirāmākṣi (read *kṣirāmābdhi*)-*yugabāṇurtusaṃkhyayā//*
ṣatsaptāṣṭakamānena cāṣṭarṣirasasaṃkhyayā/
ṛtubāṇaśrutisamaṃ vedāgnyakṣimitaṃ kramāt//

[14] op. cit. p. 425.

[15] See article on ŚAṄKU p. 476f.

[16] Thus his etymology of *apacchāyā* is 'ombre réduite, ombre minima, ombre à midi'. The usual term for the noon-shadow in jyotiḥśāstra is *madhyacchāyā*.

[17] This problem still remains unsolved.

[18] *HAMA* p. 738.

[19] After the enumeration of these shadow-lengths, the author of the *Viśvakarmavāstuśāstra* says, 'This is the method of the determination of the east in the region south of the Vindhyas.' He thereafter gives tables for the Āryāvarta and Brahmāvarta, but they are too corrupt to be recovered.

[20] Pingree (1973), p. 5f.

[21] *Arthaśāstra* II, 20, 39, and *Śārdūlakarṇāvadāna* p. 54f. al-Bīrūnī (*INDIA* p. 339) refers to the same table.

[22] op. cit. p. 419.

[23] *HAMA* p. 736–746, *EAC* p. 209–215.

[24] *HAMA* p. 736 footnote 3.

[25] *HAMA* p. 737.