Kātyāyana Śulvasūtra : Some Observations

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Abstract

The Kātyāyana Śulvasūtra has been much less studied or discussed from a modern perspective, even though the first English translation of two adhyāyas (chapters) from it, by Thibaut, appeared as far back as 1882. Part of the reason for this seems to be that the general approach to the Śulvasūtra studies has been focussed on “the mathematical knowledge found in them”; as the other earlier Śulvasūtras, especially Baudhāyana and Āpastamba substantially cover the ground in this respect the other two Śulvasūtras, Māṇava and Kātyāyana, received much less attention, the latter especially so.

On the other hand the broader purpose of historical mathematical studies extends far beyond cataloguing what was known in various cultures, rather to understand the ethos of the respective times from a mathematical point of view, in their own setting, in order to evolve a more complete picture of the mathematical developments, ups as well as downs, over history.

Viewed from this angle, a closer look at Kātyāyana Śulvasūtra assumes significance. Coming at the tail-end of the Śulvasūtras period, after which the Śulvasūtras tradition died down due to various historical reasons that are really only partly understood, makes it special in certain ways. What it omits to mention from the body of knowledge found in the earlier Śulvasūtras would also be of relevance to analyse in this context, as much as what it chooses to record. Other aspects such as the difference in language, style, would also reflect on the context. It is the purpose here to explore this direction of inquiry.

The performance of the yajnas in the Vedic period involved construction of altars (vedī) and fireplaces (citi or agni) in a variety of intricate shapes, such as birds, tortoise and others, of quite large sizes; the dimensions of the vedīs often extended to over 100 feet and the agnis could be 15 feet and 20 feet, or more, in width and length. This warranted detailed description of procedures for their construction,
which is the subject of the Śulvasūtras, which are parts of the Kalpasūtras associated with the yajurveda. Apart from the direct aspect of step by step description in the form of manuals, the Śulvasūtras also include enunciation of various geometric principles involved, thereby setting up a body of geometric ideas and framework.

The different śākhās (branches) of the Vedic people had their respective versions of Śulvasūtras, though, as may be expected, a degree of intrinsic unity may be seen in their overall contents. Notwithstanding the fact that there were a large number of śākhās, possibly in hundreds, only eight (or nine?) Śulvasūtras with mathematical content have been known in our times. Baudhāyana, Āpastamba, Māṇava, Maitrāyaniya, Varāha, Satyāśādha, and Vādul associated with the Kṛṣṇa yajurveda, and a sole Kātyāyana Śulvasūtra associated with śukla yajurveda are known. Of these, Āpastamba, Varāha, and Vādul are literally the same [6]. (???) Māṇava and Maitrāyaniya are understood to be versions of each other (though a detailed comparison does not seem to have been made yet). Baudhāyana, Āpastamba, Māṇava, and Kātyāyana Śulvasūtras are independent in overall character, even though, as noted above, there are many commonalities.

The dates of the Śulvasūtras are uncertain; according to Kashikar, as quoted in [7], the following ranges may be associated with the composition of the respective Śulvasūtras: Baudhāyana and Vādul (800 - 500 BCE), Āpastamba and Māṇava (650 - 300 BCE) and Kātyāyana, Satyāśādha and Varāha (300 BCE - 400 CE). There have also been other suggestions in this respect (see [11] for a discussion on this), placing Baudhāyana around 5th or 6th century BCE, Āpastamba around 5th and 4th century BCE, Māṇava between them, and Kātyāyana around 350 BCE. However all dates seem to be quite speculative, and there do not seem to be dependable inputs on the issue.

The Śulvasūtras are composed in the sūtra (aphoristic) style, mostly in prose form, though parts of some of Māṇava and Kātyāyana Śulvasūtras are found to be in verse form. The texts have been divided by later commentators into convenient segments, treated as individual sūtras, with numbers attached, and grouped into Chapters. As presented in [11] Baudhāyana has 21 Chapters adding to 285 sūtras, Āpastamba has 21 Chapters adding to 202 sūtras, Māṇava has 16 Chapters adding to 228 sūtras, and Kātyāyana has 6 Chapters adding to 67 sūtras.[1]

It is an enigma in the subject that the Baudhāyana Śulvasūtra which is the oldest happens to be the most systematic and comprehensive one in many ways. While the others do have some things in addition in certain respects, there are

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1 An extra chapter of Kātyāyana is found in the version given in [6].
some crucial things that are omitted, and one also senses in them a general lack of harmony in the presentation. It is almost as if the seeds of eventual decline are embedded into the Śulvasūtra literature, though indeed this would be a rather simplistic view to take.

There have been many pre-modern commentaries on the Śulvasūtras, and they have proved helpful in understanding the original Śulvasūtras; (unfortunately even the dates of the commentaries can not be ascertained). There are commentaries of Dwārakānātha Yajwa and Venkateswara Dikṣīt on Baudhāyana, of Kapardiswāmī, Karavinda Swāmī and Sundararāja on Āpastamba, and of Karka and Mahīdhara on Kātyāyana (no pre-modern commentaries are known on Mānava Śulvasūtra.)

The Śulvasūtras became part of the modern global scholarship through the works of European scholars, producing translations and edited versions of them in European languages. George Thibaut published an English translation of Baudhāyana Śulvasūtra and the commentary of Dwārakānātha Yajwa, in the journal *Pandit*, published from Benaras, during 1874 - 76. Edmund Burk brought out a translation of the Āpastamba Śulvasūtra in German in 1901. Translation of Mānava Śulvasūtra was produced by J.M. van Gelder in 1964. There have also been various subsequent studies of these Śulvasūtras, by western as well as Indian scholars. An English translation of all the four Śulvasūtras, with commentaries, was brought out by S.N. Sen and A.K. Bag [11] in 1983.

On the whole the Kātyāyana Śulvasūtra has been much less studied or discussed in modern writings, even though the first English translation of two adhyāyas (chapters) from it, by Thibaut, appeared as far back as 1882. Part of the reason for this seems to be that the general approach to the Śulvasūtra studies has been focussed on the mathematical knowledge from the tradition as a whole; indeed, many writers do not make adequate distinction between individual Śulvasūtras in the overall discourse. Since the earlier Śulvasūtras, especially Baudhāyana and Āpastamba substantially cover the ground in this respect the other two Śulvasūtras, Mānava and Kātyāyana, received much less attention, the latter especially so. On the other hand, for a fuller understanding from a historical point of view it would be important to study the Śulvasūtras with attention to their individual identities, comparisons between them etc.

Our aim here will be to discuss the Kātyāyana Śulvasūtra in this overall context, concentrating on its specialities in relation to the earlier Śulvasūtras, especially Baudhāyana Śulvasūtra. Special significance is lent to this by the fact that Kātyāyana is from substantially later times, towards the fag end of the Vedic pe-
period, after which the *yajnas* lost their sheen, as a historical phenomenon, though some feeble remnants of the idea are seen embodied in the later day Hindu ritual practices, including in our times. We shall however content ourselves with comparisons of the technical mathematical aspects, with some modest hints of their possible significance. The differences in various individual aspects would perhaps have various possible explanations, or they could even be coincidental. However it seems worthwhile to “identify” them so that eventually a more comprehensive picture may emerge, throwing light on broader historical issues relating to the transformation of the Śulvasūtra literature over its period, and in turn of the Vedic people.

1 The general features

One of the most striking distinctive features of the Kātyāyana Śulvasūtra is its rather small size compared to the others (as the alert reader may have noted from the figures mentioned above in this respect). What is this economy in aid of? Broadly speaking the difference in size is accounted for by the fact that Kātyāyana does not go into much detail of the construction of the individual *citis*, on which Baudhāyana, for instance, expends considerable amount of space, many chapters in terms of the later organization of the text. Kātyāyana Śulvasūtra is largely focussed on “theory”, though there are some parts touching upon arrangement of the *vedis* and specific features of certain *citis*. Why was such a policy adopted? It would seem that the practice of *yajnas* become too diffuse for it to be worthwhile to go into the details, and it was considered best to confine to discussing “general principles”. Notwithstanding the small size, one does not find “stinginess” in the discussion of the mathematical parts. In fact in some cases there is a lingering discourse on what may be considered quite elementary. An example, though rather an extreme one, is the part with the sutra translated as “Square on a side of 2 units is 4, on 3 units it is 9 and on 4 units it is 16.” which is then followed by the general statement for integers and then again separately for select fractions $\frac{1}{2}, \frac{1}{3}$ and $\frac{1}{4}$ for the length of the side.
2 Presentation of measures

The Baudhāyana Śulvasūtra gives at the outset (in sūtra 1.3, right after two sūtras which are in the nature of an “Abstract” for what is to follow) names of length measures with various magnitudes. There are 18 of them, the smallest being tila (sesame seed) is \( \frac{1}{34} \)th of an aṅgula (finger) and the largest one is īṣā (pole) which is 188 aṅgulas; the commonly occurring large unit however is puruṣa (man), which is 120 aṅgulas.\(^3\) The aṅgula measure was about \( \frac{3}{4} \)th of an inch, or about 1.9 centimetres. Many of the units occur infrequently, only in the description of specific vedis.

Kātyāyana Śulvasūtra involves only 9 units, all from Baudhāyana’s list, except that a term vitasti is used for a measure of 12 aṅgulas, which is pūḍeśa in Baudhāyana, and pada is also taken to be same measure (12 aṅgulas). The units range only between the aṅgula to īṣā, thus excluding in particular the fine unit measures añu and tila; these are also absent in Āpastamba and Mānava Śulvasūtras. Unlike in the Baudhāyana Śulvasūtra no systematic listing of the units is found in Kātyāyana Śulvasūtra. On the face of it this may suggest a greater standardisation of units over the period, but on the other hand it could also be because Kātyāyana does not deal with many practical situations as involved in Baudhāyana. The fact that the small units do not appear in Kātyāyana, as also in Āpastamba and Mānava Śulvasūtras, shows that they were not part of the practical need in the Vedic practices, and feature in Baudhāyana on account of specific theoretical preoccupations, corroborating Thibaut’s hypothesis connecting tila to a term in the expression for \( \sqrt{2} \). The theoretical inclination seems to have been lost over a period.

3 Cardinal directions

Unlike the earlier Śulvasūtras Kātyāyana gives explicitly a prescription for locating and fixing the cardinal directions, over any day. The east-west line is obtained as the line joining the two points on a circle drawn around the base of a pole where the shadow of the tip of the pole falls on the circle in the course of a day. The north-south line is then obtained through a process of drawing a perpendicular to

\(^{2}\)It was postulated by Thibaut (see [12], page 15) that the unit owes its origin to the fact that they had a formula for \( \sqrt{2} \) involving the fraction \( \frac{1}{7} \).

\(^{3}\) Many of the intermediate units do not bear a simple fractional relation with puruṣa however; e.g. a bāhu is 36 aṅgulas, a yuga is 86 aṅgulas, etc.
the east-west line; the process consisted of tying the ends of a rope to two poles along the east-west line, stretching the rope on either side of the line by holding it at its midpoint, and then joining the two points marked by the midpoint on either side.

One may wonder how the cardinal directions were fixed in the earlier times, especially since from the beginning they have been very important to the śulva constructions, in terms of the spiritual motivation, and the description of the constructions has typically been with reference to the east-west line. It has been suggested that it was determined by the shadow of the pole on the equinox day, and verified by the rising and setting points of the the star Kr̥ttikā. Interestingly, even though the method as above is explained at the outset of Kātyāyana Śulvasūtra, in Chapter 7 of it there is a verse (Chapter VII, verse 35) about determining the East as the direction of rising of the stars Kr̥ttikā, Śravaṇa or Puṣya or as the midway of the directions of rising of Čitrā and Śvātī. Presumably both procedures coexisted, and used for confirmation of each other; one wonders however why then they were not mentioned together. Notwithstanding the reasons for this and whatever their mutual role in practice, the procedure as above marks a significant advance from a broader mathematical point of view.

4 Construction of rectilinear figures

Towards construction of the basic figures needed to be drawn, viz. rectangles, isosceles triangles, symmetric trapezia, with prescribed sizes, the Śulvasūtras principally describe the steps for drawing perpendiculars to the line of symmetry (such a line was a common feature of the figures involved, it being along the east-west direction); these are however packaged into complete procedures, as in a manual, for drawing the desired figures; see [1] for a discussion on this.

Baudhāyana’s well-known construction of the square involves the method of drawing a perpendicular that is now a familiar compass construction in school geometry; given a line and a point on it, at which the perpendicular is to be drawn to the line, one picks two points on the line that are equidistant from the point and located on opposite sides, and draws arcs with centres at the points with radius greater than the distance from the point - the arcs intersect in two points, one on each side of the line, and joining them provides the desired perpendicular to the line passing through the given point. In this form this method is absent in Kātyāyana, though a variation may be said to be involved in Kātyāyana’s prescri-
tion for locating the north-south direction, after the east-west direction is drawn, as mentioned above. On the whole during the entire śulva period it was not common to use the compass construction as above for drawing perpendiculars, and it seems to have disappeared by the time of Kātyāyana. A method, known as Nyancana (also called Niranchana) method, was more prevalent, and in Kātyāyana it appears as the “canonical” method for drawing perpendiculars. The method is based on the converse of Pythagoras theorem, that in a triangle with sides of lengths \(a, b, c\) if \(c^2 = a^2 + b^2\) then the sides with lengths \(a\) and \(b\) are perpendicular to each other\(^4\) see [1] for details on the method and its convenience as a tool. For the \(a, b, c\) as above one uses what we now call Pythagorean triples, the three being integers such that \(c^2 = a^2 + b^2\). The same of two such triples, \((3, 4, 5)\) and \((5, 12, 13)\), are involved in the constructions in Baudhāyana and Kātyāyana Śulvasūtras, using Nyancana. Baudhāyana includes a list with 5 primitive Pythagorean triples, including the above and also \((8, 15, 17)\), \((12, 35, 37)\) and \((7, 24, 25)\), though they were not adopted for use with the Nyancana method (they are noted right after the statement of the Pythagorean theorem, and presumably meant as illustrations of the theorem - see [1]). In Kātyāyana there is no mention of any of these other triples (or of other new ones), though in Āpastamba we find four of the above triples, excluding \((7, 24, 25)\), used in the construction of the Mahāvedi by the Nyancana method.

5 Pythagoras theorem and its applications

The most notable feature of the Śulvasūtras in terms of geometric theory is the statement of the so called Pythagoras theorem. This stands out especially in the context of the fact that some of them, especially Baudhāyana, possibly predate Pythagoras. Actually neither the notion of a right angle nor of a right angled triangle are found in the Śulvasūtras, as concepts; of course right angled triangles appeared as parts of various figures, and were implicit in the Nyancana operations, but were not identified separately. Thus the statement of the Pythagoras theorem occurs not with respect to right angled triangles, but rather with reference to rectangles. A close translation of how it is stated in Baudhāyana would be “the diagonal of a rectangle makes as much (area) as (the areas) made separately by the base and the side put together”. The same statement also appears in Kātyāyana

\(^4\)It was believed at one time that the ancient Egyptians also adopted such a method, but it has subsequently been discounted - see [2]. In the case of the Śulvasūtras however such a method is seen all over the place.
(sūtra 2.7) where it is followed by a clause “itī kṣetrajnānam”. The term kṣetra involved in this has been translated as “area” by Thibaut, but as “figure” by Datta [2]. It is argued in [11] that Śulvasūtras use the term bhūmi for area, so the expression as above means “this is the knowledge about plane figures”. Whatever be precise nuance of the meaning, the clause is evidently intended to emphasize the importance of the statement to the reader. In this respect it has a pedagogical value which seems significant.

The Pythagoras theorem is also applied in the Śulvasūtras for constructing squares with area equal to the sum of areas of two given squares (including doubling of a square, called dvikaraṇi which is described separately), and the difference of areas of two given squares (with unequal areas). The constructions, which are of course a direct application of the Pythagoras theorem, are illustrated in the following Figure; see [1] for details.

![Figure 1: The thick lines give the sides of the squares with areas equal to the sum and difference, respectively, of two given squares, with bases PA and PB as in the figure.](image)

The procedure for “squaring” of the difference of two squares is also used in the Śulvasūtras, except Mānava Śulvasūtra, for squaring a rectangle, by first expressing it as a difference of two squares (by moving around half of the extra part on the longer side); see [1] for details.

The augmentation of squares was used systematically in the Śulvasūtras for replicating given figures in larger size, by simply enhancing the size of the reference unit by the desired amount; e.g. to produce a replica of a figure with area $7\frac{1}{2}$ puruṣa to one with area $8\frac{1}{2}$ puruṣa, as was required, the unit would be changed
in a way that the area will increase by a factor of $1 + \frac{2}{15}$; the side for this would be obtained as a combination of the original unit with a square of area $\frac{2}{15}$th of it. In fact this problem may have been the inspiration for their discovery of the Pythagoras theorem; see [1] for a discussion on how they may have arrived at the theorem.

While the conceptual framework in this respect is common to all the Śulvasūtras, Kātyāyana is seen to deal with some of the features involved more dexterously than in the earlier Śulvasūtras. The use of the method combining squares and rectangles seems to have become by now an art, with the individual steps dealt with almost casually. In the construction of the droṇaciti (śūtras at the beginning of Chapter 4) for instance, it is quite casually prescribed to divide the square into 10 parts and to make one of them into a square and the rest into another square. On the problem of augmenting the unit for the purpose as described above, Kātyāyana introduces a “rule of thumb” method; it however does not seem to conform to the standard stipulations accurately; apparently it was decided to pay a price in terms of accuracy in aid of simplicity of execution.

There is one especially notable mathematical observation found in Kātyāyana in this context. It is the procedure to produce a square with area equal to any desired multiple of the unit. In the general Śulvasūtras spirit this could be done by augmentation of squares of smaller squares, starting with complete squares. Kātyāyana proposes a direct method, that it be constructed as the altitude of an isosceles triangle whose base is one less than the desired number (of area multiple) and the two equal sides add to one more than the desired number. This is an interesting application of Pythagoras theorem and the identity $\frac{1}{4}(n+1)^2 - \frac{1}{4}(n-1)^2 = n$. While there is indeed nothing quite like an abstract “variable” $n$ in the modern sense involved, the identity seems to have been realised in terms of the desired number of unit squares to be combined ($yāvatpramāṇāni samacaturasrāṇī$), presumably by inspection of square grids.

6 The square and the circle

Kātyāyana Śulbasūtra gives the same method as Baudhāyana for “transforming” a square into a circle, namely for producing a circle with area equal to that of the

\[ \text{In [11], both in the translation of the sūtra for this (4.2 on page 123) and the commentary on it page 268, it is said that the square is to be divided into 100 parts; that interpretation is however incorrect, as can be seen from [12] and [13].} \]
given square; it may be recalled that this consists of taking half the diagonal of the square, dropping it from the centre along the midriff, and drawing the circle with radius which includes half the side and a third of the part jutting out, namely $PR$ as seen in the Figure 2 (see [1] for details).

![Figure 2: Circling the square: the thick line PR is given as the radius of the desired circle with area equal to that of the square ABCD.](image)

While the procedure is interesting (especially in its application of an intuitive “mean-value principle”) it is not very accurate. The area of this circle for the unit square works out to be $1.0172524...$, about 1.7% more than that of the original square, and a computation of the value of $\pi$ with it comes to $3.088...$). Despite this, there seems to have been no change made from Baudhāyana to Kātyāyana. On the other hand the Mānava Śulvasūtra, though less “sophisticated” than either of these, and substantially older than Kātyāyana, seems to contain a more accurate procedure for producing a circle with the area of a given square; see [1]. The Maitrāyaṇīya Śulvasūtra, which is akin to Mānava Śulvasūtra gives a construction which involves taking the radius of the desired circle to be $\frac{9}{16}$ times the side of the given square; see [1]. Both of these involve only about $\frac{1}{2}$ percent error.

The converse problem of “squaring the circle” viz. finding a square with the area of a given circle is also considered in the Śulvasūtras. Typically the treatment is not geometric, but by assigning a numerical relation between the side of the desired square to the diameter of the given circle; according to [5], sutra 3.2.10
from Mānava is in fact a geometric construction for squaring the circle, but we shall not go into it here; see [1]. Baudhāyana Śulvasūtra gives two formulae for squaring the circle. The first one gives the value for the side of the square with area equal to that of the circle with unit radius to be

\[
\frac{7}{8} + \frac{1}{8 \times 29} - \frac{1}{8 \times 29 \times 6} + \frac{1}{8 \times 29 \times 6 \times 8}.
\]

(*)

The area of the square with that as the side works out to be 3.088..., about 98.3% of the actual value. The second prescription consists of taking \(\frac{13}{15}\)th of the diameter of the given circle for the side of the desired square. The second is qualified by Baudhāyana as an “incidental” (anītya) method for squaring, signifying that not wishing to use the cumbersome formula one could do with this approximate one. Curiously, only this crude formula, giving a value that is smaller by 4% has been described in Kātyāyana Śulvasūtras (as also Āpastamba) for the purpose.

7 The square root of 2

Three of the four Śulvasūtras, Baudhāyana, Āpastamba and Kātyāyana, describe a formula for \(\sqrt{2}\) (in words) which corresponds to expressing the value as

\[
1 + \frac{1}{3} + \frac{1}{3 \times 4} - \frac{1}{3 \times 4 \times 34}.
\]

In decimal expansion the value works out to be 1.4142157..., and is noted to be accurate upto 5 decimal places.\(^6\)

The sūtra giving the formula is followed by “śāviśeṣaḥ” in Baudhāyana, “sa viśeṣaḥ” in Āpastamba and “sa viśeṣa iti viśeṣaḥ” in Kātyāyana. The word viśeṣaḥ means “extra”. However it does not refer to any comparison with an accurate value of \(\sqrt{2}\). It is known from the tradition of śulvavidś that viśeṣaḥ was used as a technical term for the difference between the dvikaraṇī, namely \(\sqrt{2}\), and the unit (signifying what comes up as extra in terms of the side, while doubling a square), and in conjunction with it sāviśeṣaḥ stood for the dvikaraṇī itself. Occurrence of the phrase following the sūtra is what tells us what the number in the sūtra stands for (the rest of the sūtra only provides a number and contains no reference to what it is).

\(^6\) It may be recalled here that the Babylonians also had a similarly close approximation for \(\sqrt{2}\), as 1.4142129..., expressed in the sexagesimal system that they used.
In [11] the second part “iti viśeṣaḥ” has been translated as “this is approximate.” (curiously, reference the sūtra is missing from the commentary section in the book); see also [9], pp. 21. However, there does not seem to be adequate justification for interpreting or connecting the part with an assertion about the value being approximate. Khadilkar [6] translates the part, in Marathi, as “Ha dvikaraṇī ūharavinyaca nirala prakāra.”, or “This is a different method of determining dvikaraṇī”[7] The Karka bhāṣya commentary seems to confirm this; see [6] for the commentary. The overall context seems to favour this interpretation. From all indications the close to accurate value of $\sqrt{2}$ was computed, by Baudhāyana or around the time, not for practical application, for which it is not at all suitable, but to facilitate the computation of the intricate formula for squaring the circle, (*) as above; see [10] and [1] for detailed argument in this respect. However, subsequent to Baudhāyana somehow no one seems to have been interested in that formula, they being content to use the simple proportion of 13:15 for the desired ratio. The formula for $\sqrt{2}$ then became a curiosity, bereft of its original significance (a nice-looking formula propounded by masters of a bygone era). It was thus a different, unusual, formula for the dvikaraṇī, which actually for their purpose they could simply measure out from the diagonal with a rope.

There is also another interpretation possible. As noted above viśeṣaḥ stands for the excess of the dvikaraṇī over the unit. The sūtra thus seems to say that viśeṣaḥ is such that sa viśeṣa is given by the previous expression. This is suggested by the translation in [7], where iti viśeṣaḥ is translated, in Hindi, as “Yaha višeṣa ki vyākhya hai”. It may also be recalled here that the word “iti” in Sanskrit corresponds to “in this manner”, “thus” or “as you know” (see [8]) which fits well with this interpretation.

Of course it would have been known, at least when the formula $\sqrt{2}$ was first established, that it is not exact. A formula of this kind had to be arrived at in some way (see [1] for a discussion on the possibilities in this respect), and whichever way it was, it would have been clear that an adjustment remained to be made. There is however no indication that they considered it a significant fact worth noting.

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[7] My translation from the Marathi version.
8 Concluding remarks

On the whole one notices that in the directions which were applicable to the practical issues they met with, in terms of constructing various rectilinear figures with conditions on the area etc., there was progress in terms of simplifying the procedures and devising new ones. However not much attention seems to have been paid, collectively, to preserving interesting findings, even those with high aesthetic qualities, that were not directly involved in regular practice. In some ways this could be the result of a diffused organisation, with feeble communication and inadequate opportunities for intellectual interaction.

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References

[1] S.G. Dani, Geometry in the Śulvasūtras, Studies in the history of Indian mathematics, 9 - 37, Cult. Hist. Math. 5, Hindustan Book Agency, New Delhi, 2010.

[2] Bibhutibhusan Datta, Ancient Hindu Geometry: The Science of the Śulba, Calcutta Univ. Press. 1932; reprint: Cosmo Publications, New Delhi, 1993.

[3] R.J. Gillings, Mathematics in the Time of Pharaohs, Dover Publications, New York, 1972.

[4] R.C. Gupta, Śulvasūtras: earliest studies and a newly published manual, Indian J. Hist. Sci. 41 (2006), 317 - 320.

[5] Takao Hayashi, A new Indian rule for the squaring of a circle: Mānava Śulvasūtra3.2.9-10, Ganita Bharati 12 (1990), 75-82.

[6] Shri. Da. Khadilkar, Kātyāyana śulba sūtre (in Marathi), Maharashtra Rajya Sahitya Sanskrity Mandal, Mumbai, 1974.

[7] Raghunath P. Kulkarni, Char Shulbasūtra (in Hindi), Maharshi Sandipani Rashtriya Vedavidya Pratishthana, Ujjain, 2000.

[8] Monier Monier-Williams, A Sanskrit-English Dictionary, Motilal Banarasidass, 2002.
[9] Kim Plofker, Mathematics in India: 500 BCE - 1800 CE, Princeton University Press, 2008.

[10] A. Seidenberg, The ritual origin of geometry, Archive for History of Exact Sciences (Springer, Berlin) Vol. 1, No. 5, January 1975. (available at: http://www.springerlink.com/content/r6304ku830258l85/)

[11] S.N. Sen and A.K. Bag, The Śulbasūtras, Indian National Science Academy, New Delhi 1983.

[12] G. Thibaut, The Śulvasūtras, The Journal, Asiatic Society of Bengal, Part I, 1875, Printed by C.B. Lewis, Baptist Mission Press, Calcutta, 1875.

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