The Metrology behind Harappan Town-Planning

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Abstract

The existence and use of Harappan linear units have remained a riddle. Harappan town planning, in particular, has not so far been known to have used precise units, although it displays elaborate geometry. This article proposes that the site of Dholavira, in the Rann of Kachchh, enables us to calculate a possible linear unit used to lay out the fortifications. This unit, which works out to 1.9 m, is then related to a proposed Harappan angula of 1.76 cm, with a factor of 108 between the two, as indicated in later classical literature.

Besides other Harappan sites, independent research at early historical and historical sites and structures — e.g., Taxila, Shishupalgarh, Thimi and the Delhi Iron Pillar — is quoted as confirmation of the proposed system — an important case of continuity between India's two urbanizations.

Dholavira's Plan and Proportions

Dholavira (23°53'10" N, 70°13' E) is probably the most spectacular Harappan site to be seen after Mohenjo-daro, and, at 48 hectares, the second largest in India (after Rakhigarhi in Haryana). Discovered by the late Jagat Pati Joshi in the 1960s on the Khadir island of the Rann of Kachchh, it was excavated in the 1990s under the direction of R.S. Bisht of the Archaeological Survey of India. The Harappans' motivations in setting up this large city in such a harsh and forbidding environment must have been intimately related to access to raw materials, craft production and trade. There is evidence that the Rann of Kachchh was navigable in Harappan times, which would have given Dholavira access to the sea.[1] As a regional capital, Dholavira must have exerted a measure of control over the hundreds of smaller Harappan sites dotting Kachchh, Saurashtra and mainland Gujarat. It flourished during the Mature Harappan phase, that is, between 2600 and 1900 BCE.

Even if the climate might have been slightly more congenial than it is today, the establishment of such a city in this location is a feat of planning, engineering, labour control and execution, especially in the field of water harvesting and management: Dholavira's colossal water structures, covering some 17 hectares and often interconnected through underground drains, were the *sine qua non* of the city's survival through the year.

Like most Harappan sites, Dholavira followed a strict plan, but one of its kind with multiple enclosures. While Harappan town-planning is often based on an acropolis / lower town duality (as at Mohenjo-daro and Kalibangan), Dholavira's plan (Fig. 1) is triple: an acropolis or upper town consisting of a massive "castle" located on the city's high point and an adjacent "bailey"; a middle town, separated from the acropolis by a huge ceremonial ground; and a lower town, part of which was occupied by a series of reservoirs. (Terms such as "castle", "bailey", etc., are those of the excavator.)

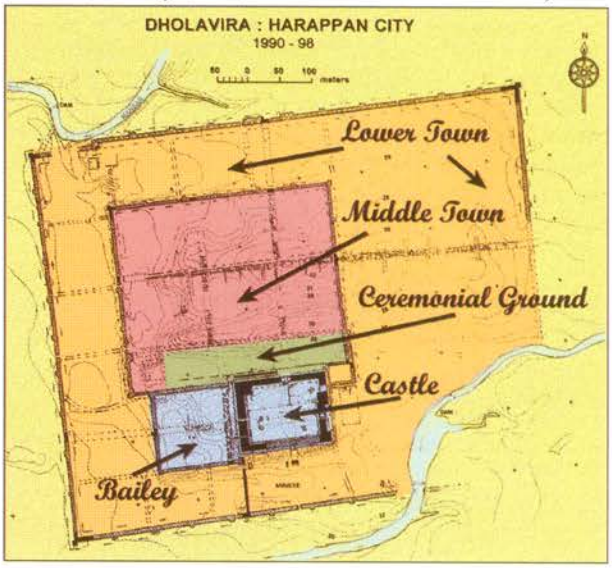

Fig. 1. Plan of Dholavira (adapted from Bisht 1999).

A mere look at the plan suggests a complex conceptual background. Can we make some sense of the concepts and rules Dholavira's urban architects followed? To do so, we need to study the dimensions of the various fortifications, which were precisely measured by the ASI team. Table 1 summarizes them,[2] with a maximum margin of error of 0.5%.[3] Importantly, the three longest dimensions have since been confirmed by GPS readings.[4]

Dimension	Measurement (in metres)	
	Length	Width
Entire city	771.1	616.85
Middle town	340.5	290.45
Ceremonial ground	283	47.5
"Castle" (inner)	114	92
"Castle" (outer)	151	118
"Bailey"	120	120

Table 1: Dholavira's dimensions

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It became immediately clear to the excavator that these dimensions obeyed precise ratios or proportions. Bisht highlighted some of them as follows (I have added in parentheses the margins of error calculated on the basis of Table 1 and rounded off to the first decimal):

1. The city's length (east-west axis) and width (north-south) are in a ratio of 5:4 or 1.25 (0.0%, a perfect match).
2. The "castle" also reflects the city's ratio of 5:4 (0.9% inner, 2.4% outer).
3. The "bailey" is square (ratio 1:1).
4. The middle town's length and breadth are in a ratio of 7:6 (0.5%).
5. The ceremonial ground's proportions are 6:1 (0.7%).

All but one ratios are verified within 1%, an excellent agreement considering the irregularities of the terrain. In two papers,[5] I worked out a few other important ratios at work in Dholavira, some of which would have been chosen by the town-planners in order to define the whole city geometrically, others following as consequences of those initial choices. The principal ratios are summarized in Table 2 and Fig. 2. Not only are the margins of error very small, but the repetition of ratios 5:4 and 9:4 cannot be accidental.

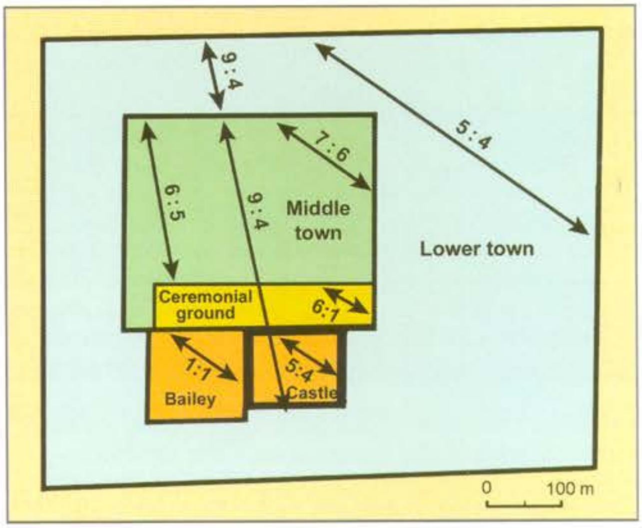

Fig. 2. Main ratios at work in Dholavira's plan

Dimension	Ratio	Margin of error(%)
Entire city*	5:4	0.0
"Castle", inner*	5:4	0.9
"Castle", outer*	5:4	2.4
"Bailey"*	1:1	0.0
Middle town*	7:6	0.5
Ceremonial ground*	6:1	0.7
Castle's outer to inner lengths**	4:3	0.7
Middle town's length to castle's internal length**	3:1	0.4
Middle town's length to castle's outer length**	9:4	0.2
City's length to middle town's length**	9:4	0.6
Middle town's length to ceremonial ground's length**	6:5	0.3
* = proposed by R. S. Bisht ** = proposed by Michel Danino		

Table 2. Dholavira's ratios and margins of errors

Dholavira's Master Unit of Length

How were Dholavira's town planners able to impose such a set of precise ratios and dimensions on the ground? Two assumptions appear reasonable at this stage: (1) they must have used a standard of length; (2) they chose integral (or whole) multiples of this standard for as many of the main dimensions as possible. I propose that there is a simple way to calculate the main linear unit used at Dholavira.

Let us call it "D" for Dholavira. Elsewhere,[6] I used a simple procedure to calculate the largest possible value of D that will result in most of the city's dimensions being expressed as integral multiples of D. The procedure, briefly put, consists in algebraically expressing the smallest dimension in our scheme (i.e., the average width of the castle's western and eastern fortifications) as a multiple of the unknown unit D (or nD, n being an integer); then, using all available ratios, to express all larger dimensions in terms of nD. We find, of course, that a few dimensions are not integral but fractional expressions of nD. To make those fractions disappear, we choose "n" as the least common multiple of their denominators. It turns out that with n = 10, all fractional results disappear, except one. Going back to our initial formula, the width of the castle's western and eastern fortifications, which we expressed as nD, is now 10 D. Bringing into play the proportions listed above, we can express all but one dimensions as multiples of D. Fig. 3 summarizes the findings.*

We now only need to determine the value of D, which is simply derived from the city's length: if 771.1 m = 405 D, then D = 1.904 m or 190.4 cm, which we may round off to 1.9 m.

Starting from this value and calculating the theoretical dimensions backward using Fig. 3, we can compare them with the actual dimensions. Table 3 lists the results, as well as the margins of error between theoretical and actual dimensions. The latter are remarkably modest, 0.6% on average (the highest being, again, in the outer dimensions of the "castle"). These almost perfect matches appear to rule out the play of chance.

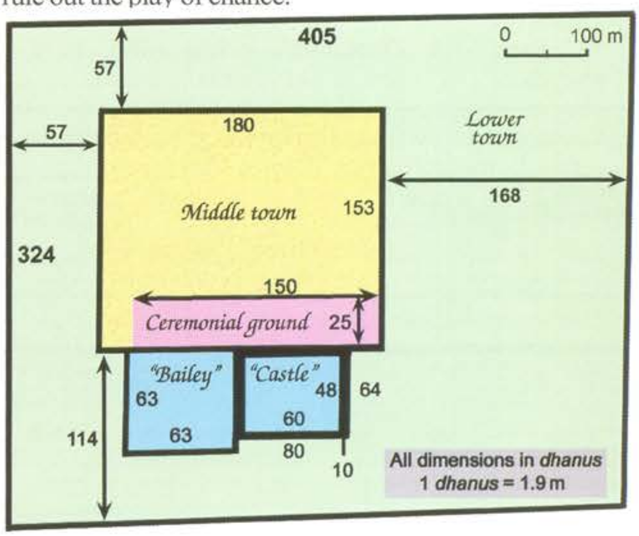

Fig. 3: Dholavira's main dimensions expressed in terms of dhanus, Dholavira's master unit of length.

Dimension	Length (in terms of unit D)	Theoretical measurement (in metres)	Actual measurement (in metres)	Margin of error (%)
Lower town's length	405	771.1	771.1	0.0
Lower town's width	324	616.9	616.85	0.0
Middle town's length	180	342.7	340.5	+0.6
Middle town's width	154.3	293.8	290.45	+1.1
Ceremonial ground's length	150	285.6	283	+0.9
Ceremonial ground's width	25	47.6	47.5	+0.2
Inner castle's length	60	114.2	114	+0.2
Inner castle's width	48	91.4	92	-0.7
Outer castle's length	80	152.3	151	+0.9
Outer castle's width	64	121.9	118	+3.2
Bailey's length & width	63	120.0	120	0.0

Table 3: Comparison between theoretical and actual dimensions.

* The exception is the middle town's width, but this is normal. If the middle town's length is, as produced by these calculations, 180 D, with a ratio of 7 : 6 between them, the width cannot be an integral multiple of D; it will be about 154.3 D. (In reality, at 290.45 m, it is almost 153 D).

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Ratios in Harappan Settlements

For whatever reasons, Harappans clearly preferred certain fixed ratios to random proportions. This is visible not just at Dholavira but at other Mature Harappan sites, as the following selective list shows (in increasing order):

* Ratio 7:6, the ratio of Dholavira's middle town, is found in the dimensions of the "assembly hall", also called "pillared hall", on the southern part of Mohenjo-daro's acropolis, which measures "approximately 23 by 27 metres".[7]

* Ratio 5:4, Dholavira's prime ratio, is found elsewhere in Gujarat at Lothal, whose overall dimensions are 280 x 225 m,[8] and Juni Kuran (just forty kilometres away from Dholavira in Kachchh), whose acropolis measures 92 x 72 m,[9] which approximates 5:4 by 2.2%. It is also reflected in Harappa's "granary"[10] of 51.2 x 40.8 m (with a precision of 0.3%) and in a major building of Mohenjo-daro's HR area[11] measuring 18.9 x 15.2 m (0.5%). Ratio 5:4 is repeated in other ways. At Dholavira, for instance, there are 5 salients on the northern side of the middle town's fortification, against 4 on its eastern and western sides (if we include the corner salients, their numbers grow to 7 and 6, which reflect the middle town's ratio). Returning to Mohenjo-daro's "pillared hall", it had four rows of five pillars each.[12] It is quite intriguing that this hall, in its dimensions (7:6) as well as rows of pillars (5:4), should reflect Dholavira's two key ratios!

* Ratio 4:3 is visible in Mohenjo-daro's "granary" (also called "warehouse"): this structure is composed of 27 brick platforms (in 3 rows of 9); while all platforms are 4.5 m wide (in an east-west direction), their length (in a north-west direction) is 8 m for the first row, 4.5 m for the central row, and 6 m for the third row.[13] It is singular that both pairs (8, 6) and (6, 4.5) precisely reflect the ratio 4 : 3.

* Ratio 3:2 is the overall ratio of Kalibangan's lower town (approximate dimensions 360 x 240 m),[14] as well as of a sacrificial pit (1.50 x 1 m).[15] It is also the ratio of three reservoirs at Dholavira: one in the "castle" measuring 4.35 x 2.95 m,[16] and two larger ones to the south of the castle.[17] We find it again (within 1%) at Mohenjo-daro in the overall platform of the "granary", which measures 50 x 33 m.[18]

* Ratio 2:1 is that of Dholavira's acropolis ("castle" and "bailey" together); it is also found at Mohenjo-daro[19] (whose acropolis rests on a huge brick platform measuring 400 x 200 m), Kalibangan[20] (acropolis of 120 x 240 m) and Surkotada[21] (overall dimensions 130 x 65 m).

* Ratio 9:4, apart from its double presence at Dholavira, is found at Mohenjo-daro's long building located just north of the Great Bath, called "block 6" and measuring approximately 56.4 x 25 m,[22] thus within 0.3%.

* Ratio 7:3 is found at Harappa's mound AB in "14 symmetrically arranged small houses",[23] each measuring 17.06 x 7.31 m (nil margin).

Fig. 4: A view of Dholavira's eastern reservoir (author's photo).

* Ratio 5:2 is that of Dholavira's colossal eastern reservoir[24] (73.5 x 29.3 m, thus with a margin of 0.3%), Fig. 4. It is also reflected, with the same high precision, in 12 rooms of Harappa's "granary", each measuring 15.2 x 6.1 m.[25]

* Ratio 11:4 is that of the secondary rock-cut reservoir "SR3"[26] found to the south of the Dholavira's "castle", 15.5 x 5.65 m, with a high degree of precision (0.2%), Fig. 5.

* Ratio 3:1 is found at Mohenjo-daro's "college" whose average dimensions are 70.3 x 23.9 m.[27]

The above few examples are summarized (with a few more) in Fig. 6. In probabilistic terms, while lower ratios (such as 7:6) could be rejected as a rough approximation of 1 and therefore of no particular significance, the higher we rise in the scale and the less tenable such an explanation will be: the intentional use of specific proportions is indisputable and has not attracted sufficient attention so far. Harappan architects and builders did not believe in haphazard constructions, but followed precise canons of aesthetics based on specific proportions.

Fig. 5: A view of Dholavira's SR3 southern reservoir (author's photo).

* Ratio 7:2 is that of Dholavira's primary rock-cut reservoir "SR3"[28] mentioned above (33.4 x 9.45 m, thus with a margin of 1%), Fig. 5.

* Ratio 6:1 is reflected not just in Dholavira's ceremonial ground but in Lothal's dockyard[29] (average dimensions 216.6 x 36.6 m).

We can also see that Dholavira's ratios are not exclusive to this site but are part of a broader Harappan tradition of town planning and architecture, whose conceptual foundations remain poorly understood.

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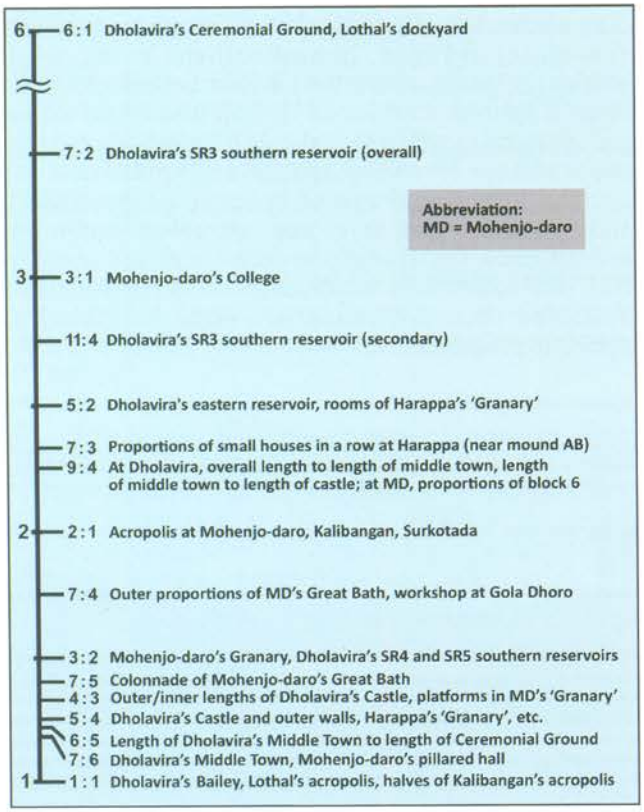

Fig. 6: A sampling of ratios found at a few Harappan sites (on a linear scale), generally with a high degree of precision.

Dimensions in Harappan Settlements

Ratios apart, we come across many dimensions of structures in Harappan settlements that can be expressed as integral multiples of our proposed Dholavira unit D = 1.9 m. A few examples are below in Table 4, while Fig. 7 illustrates the case of Mohenjo-daro's acropolis.

While every single dimension cannot be expected to be a whole multiple of D, it is striking enough that so many should turn out to be. This makes a strong case for Dholavira's unit to have been one of the standards in the Harappan world, at least as far as town-planning and architecture are concerned.

Harappan site	Structure	Dimensions in metres	In terms of D = 1.9m	Margin of error (%)
Mohenjo-daro	building in HR area	18.9 x 15.2	10 x 8	0.7, 0.2
	"college"	70.3 (length)	37	0.2
	"block 6"	56.4	30	1%
	"pillared hall"	23 x 27	14 x 12	-
	"First Street"[30]	7.6 (width)	4	0.2
Harappa	"granary"	51.2 x 40.8	27	0.2
	12 rooms of granary	15.2 (length)	8	0.2
	14 houses (mound AB)	17.06 (length)	9	0.4
Dholavira	2 stone columns (castle)[31]	3.8 (apart)	2	0.0
	middle town's major street[32]	5.75 (width)	3	0.7
	reservoirSR1[33]	30.35	16	0.2
	reservoirSR3, primary (width)[34]	9.45	5	0.5
	reservoirSR3, secondary (width)[35]	5.65	3	0.9
	reservoirSR4[36]	11.40 (max. length)	6	-
Chanhu-daro	street[37]	5.68 (width)	3	0.6
Lothal	dockyard	216.6 x 36.6	114 x 19	-

Table 4: Dimensions at various Harappan sites precisely expressed as integral multiples of D = 1.9 m. (The margin of error is included only if the published dimensions are judged precise enough).

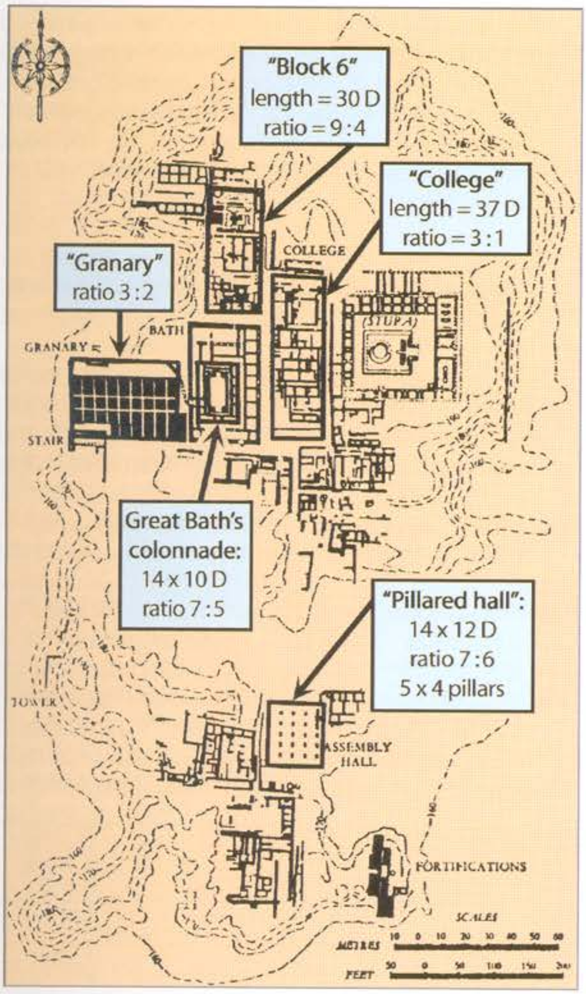

Fig. 7 : Mohenjo-daro's acropolis: a few ratios and dimensions expressed in terms of Dholavira's unit D = 1.9 m.

Dholavira's Dhanus and Angula

A unit does not exist singly: it is always part of a system. D = 1.9 m is a large unit and must have had subunits. In an attempt to figure them out, let us turn to divisions on the three known Harappan scales: those of Mohenjo-daro (6.7056 mm), Harappa (9.34 mm),[38] and Lothal (1.77 mm). The last is evidenced on an ivory scale found at Lothal, which has 27 graduations covering 46 mm. (Both S. R. Rao[39] and V.B. Mainkar erred in dividing 46 mm by 27, when the length must of course be divided by the 26 divisions formed by the 27 graduations).

Dividing D by the first two units yields no clear result. Dividing it by the Lothal unit (1904 by 1.77), we get 1075.7, or, with an approximation of 0.4%, 1080. This last number can be written 108 x 10. In other words, D can be expressed as 108 times 1.77 cm.

Let us pursue this line of inquiry: what is so special about 1.77 cm? First, let us remember that the values of the traditional digit in the ancient world, be it in Egypt, Mesopotamia, China, Greece, Japan or the Roman Empire, fluctuated between 1.6 and 1.9 cm.[40] Ten times the Lothal unit falls in that range. Then, the *Arthashastra* defines a digit (*angula* in Sanskrit) as eight widths of barley grain (2.20.6) or "the maximum width of the middle part of the middle finger of a middling man" (2.20.7).[41] Some eight centuries later, Varahamihira's *Brihat Samhita* (LVIII.2) repeats the first definition; that is the "standard" *angula* of classical India (there are indeed variations in later or regional traditions of iconometry, but they need not detain us here). Most scholars from J.F. Fleet down took the *angula* to be "roughly equating ... ¾th of an inch",[42] that is, 1.9 cm. K.S. Shukla,[43] Ajay Mitra Shastri[44] or A.K. Bag,[45] to quote just a few, endorsed this approximate value. In contrast, the metrologist V.B. Mainkar[46] traced the "development of length and area measures in India" and narrowed the value of the *angula* to 17.78 mm. He was probably the first to suggest that 10 times the Lothal unit, i.e. 1.77 cm, was almost identical to the traditional *angula*.

Moreover, a crude terracotta scale from Kalibangan was submitted to careful scrutiny by the late R. Balasubramaniam, who established that it is based on a unit of 1.75 cm.[47] This is almost the same as the Lothal unit of 1.77 cm.

Let us average the two and call 1.76 cm "A" for *angula*; we then have the following relation: D = 108 A. This is an arresting result, since the concept of "108 *angulas*" is well attested in classical India. For instance, one of the systems of units described in Kautilya's *Arthashastra* (2.20.19) fits very well in the Dholavirian scheme: "108 *angulas* make a *dhanus* (meaning a bow), a measure [used] for roads and city walls."[48] "City walls" is precisely the context in which our unit D was used at Dholavira and elsewhere. We can now propose that "D" also stands for *dhanus*.

The Harappan brick provides us with a degree of confirmation of the Lothal *angula*. In the Mature phase (and occasionally in the Early phase), most bricks follow ratios of 1:2:4 in terms of height-width-length; among several different sizes in this ratio, one dominates by far: 7 x 14 x 28 cm, measured and averaged over numerous samples (as mentioned by Kenoyer[49] and by Rottländer quoting Jansen[50]); the first dimension, 7 cm, is almost exactly 4 Lothal *angulas* (the difference being just 0.5 mm or 0.7%). So the humble brick's dimensions can be elegantly expressed as 4 x 8 x 16A.

Between the *angula* and the *dhanus*, there must have been several important subunits, and elsewhere[51] I attempted to work out a few of them; preliminary findings are that units of 4, 8, 10, 15, 16, 27 and 36 *angulas* were probably in use in Harappan times. However, this requires confirmation through more systematic studies.

Continuity of the Dholavira Scheme of Ratios and Units

The scheme of ratio and units found at Dholavira finds further echoes in historical times. The *Arthashastra* apart, "many [early texts] concentrate on the description of an image of 108 *angulas* in length."[52] The origin of the concept behind the sacred number 108 is probably multiple. It could be simply based on the human body: 108 *angulas* (1.9 m) is the height of a tall man, as specifically mentioned by Varahamihira in his *Brihat Samhita* (68.105).[53] From a different perspective, simple but compelling astronomical considerations behind 108 have been demonstrated by Subhash Kak.[54]

Dholavira's ratios must have been perceived as specially auspicious, otherwise every enclosure might as well have been square. Some of those ratios are still in use in various traditions of Vastu Shilpa. In the sixth century CE, for instance, Varahamihira wrote in his *Brihat Samhita* (53.4 & 5):

> The length of a king's palace is greater than the breadth by a quarter.... The length of the house of a commander-in-chief exceeds the width by a sixth.[55]

These two ratios, 1 + 1/4 and 1 + 1/6, are identical to 5:4 and 7:6 - very precisely Dholavira's most prominent ratios (see Fig. 2). Such a perfect double match appears to be beyond the realm of coincidence.

A recent work by Mohan Pant and Shuji Funo[56] compared the grid dimensions of building clusters and quarter blocks of three cities: Mohenjo-daro, Sirkap (Taxila, early historical, Fig. 8), and Thimi (in Kathmandu Valley, a contemporary town of historical origins). Carefully superimposing grids on published plans of all three cities (their own in the case of Thimi), the authors found that block dimensions measure 9.6 m, 19.2 m (= 9.6 m x 2), or multiples of such dimensions. This, they argue,

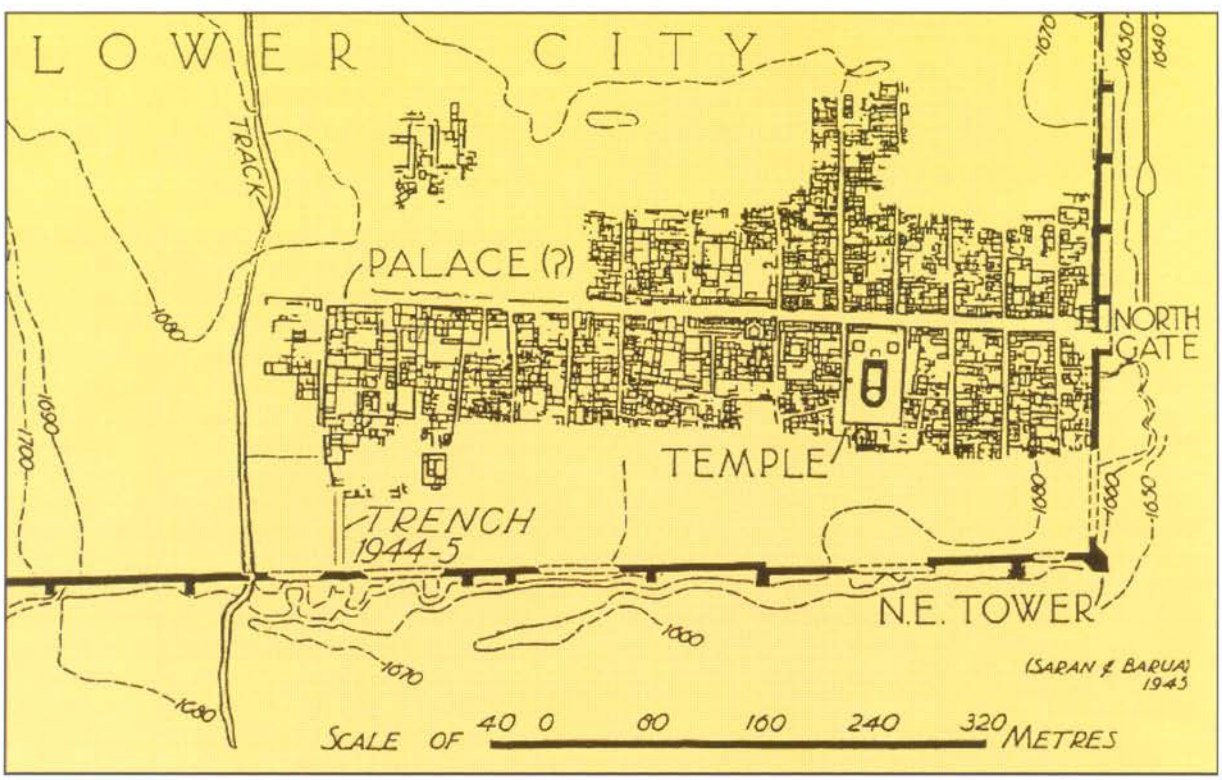

Fig. 8: Plan of Sirkap, one of Taxila's mounds. The blocks of houses are separated by regularly spaced streets, 38.4m apart (=1.92 x 20).

evokes the *Arthashastra's* unit called *rajju*, equal to 10 *dandas*. As regards the *danda*, which has four possible traditional values, the authors choose that of 108 *angulas* as prescribed in the *Arthashastra* (2.20.18-19); it is the same passage which I quoted earlier to define the *dhanus,* and the *danda* is mentioned in it as another name of the *dhanus*: for our purposes, the two terms are identical.

Pant's and Funo's unit of 1.92 m differs from mine of 1.9 m by just 1% ; in both cases, the unit was equated 108 *angulas*. Their work thus lends support to my suggestion that such concepts survived the collapse of Harappan urbanism and re-emerged in Kautilya's canons of urbanism. Is this so surprising, when we already know that the Harappans' weight system, metallurgical, agricultural and craft techniques did live on, apart from numerous religious symbols and practices?[57]

We get further confirmation of such continuity from a case study of the Delhi Iron Pillar (Qutub Minar complex) by R. Balasubramaniam,[58] who applied to it the Harappan *dhanus* and *angula* I had proposed and found they expressed the pillar's dimensions with unexpected harmony (Fig. 9): its total length of 7.67 m, for instance, is precisely 4 D; its diameter, 36 *angulas* at the bottom, shrinks to 24 *angulas* at ground level, finally to taper off at 12 *angulas* at the very top. If this were not enough, the ratio between the pillar's entire length (7.67 m) and the portion above the ground (6.12 m) is 5:4, verified to 0.2% - again, Dholavira's master ratio. This bears out once again that Harappan ratios and linear units survived the collapse of the Indus cities and passed to those of the Ganges Valley. Balasubramaniam applied the same units with excellent results to engineered caves of the Mauryan period[59] and to the Taj Mahal complex,[60] opening a new line of inquiry in classical Indian metrology.

Harappan and Classical Concepts

On a cultural level, the presence of carefully proportioned fortifications as at Dholavira might be as much a specific cultural trait as pyramids are to Egypt or ziggurats to Mesopotamia. Here, instead of erecting colossal buildings, enormous energy was spent on defining spaces: the space of the rulers and administrators (the acropolis) and the spaces for other classes of citizens. Demarcating was a vital need not for defence, but for self-definition: fortifications probably stood for authority and segregation, as Piotr A. Eltsov has recently argued too.[61]

But there may also be deeper motives at work: ratios and units apart, we can discern a few important

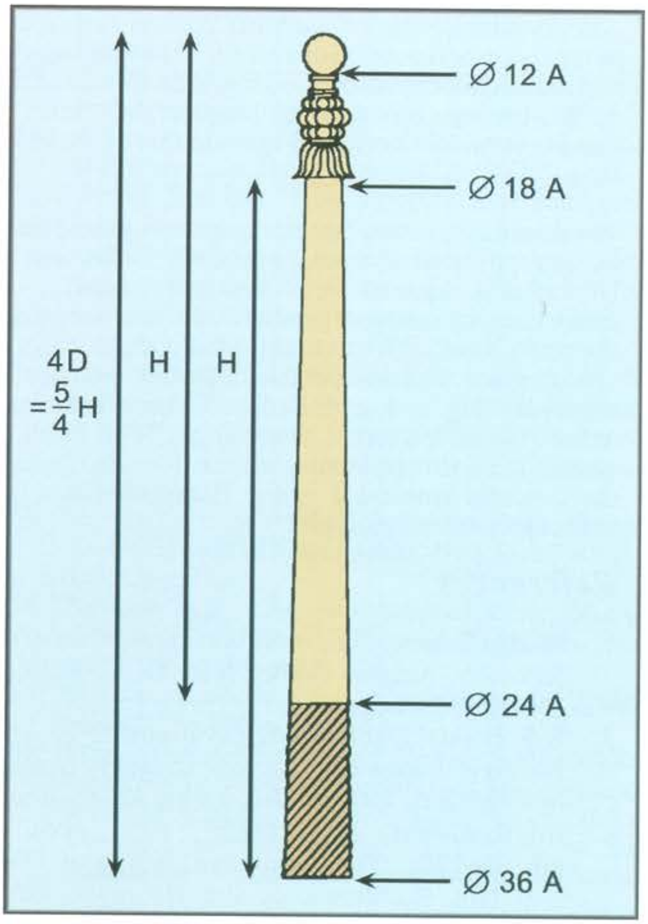

Fig. 9: A sketch on the Delhi Iron Pillar with the main dimensions expressed in terms of D = Dholavira's *dhanus* (1.9 m) and A = Dholavira's *angula* (1.76

principles underlying Dholavira's fascinating harmony, in an almost Pythagorean sense of the term. More work and data are needed to bring out those principles securely, but I proposed elsewhere[62] that the Vedic principle of *addition of a unit* is at work here: 5:4 should be read as "one unit plus one fourth", and the key ratio of 9:4, for instance, is nothing but 5:4 plus one unit. This addition to the unit of a fraction of itself can also be seen as a process of expansion, of auspicious increase symbolizing or inviting prosperity. Thus the *Manasara*, a treatise of Hindu architecture, applies this process when it specifies (35.18-20) that "the length of the mansion [to be built] should be ascertained by commencing with its breadth, or increasing it by one-fourth, one-half, three-fourth, or making it twice, or greater than twice by one-fourth, one-half or three-fourths, or making it three times."[63] The outcome is a series of ratios: 5:4, 3:2, 7:4, 2:1, 9:4, 5:2, 11:4, 3:1. Since we found all these ratios at Dholavira or other Harappan settlements, it is tempting to assume that the concept behind such auspicious ratios was the same in Harappan times.

Also found at Dholavira is another Vedic principle, that of *recursion* or repetition of a motif.[64] Thus the "castle" and the overall city share the same ratio (5:4), and 9:4 defines the expansion from the length of the "castle" to that of the middle town, and again to that of the lower town.

The thread connecting those principles was anticipated by astrophysicist J. McKim Malville, who saw in Dholavira's features "the apparent intent ... to interweave, by means of geometry, the microcosm and the macrocosm".[65] To the ancient mind, the concept of sacred space was inseparable from the practice of town-planning and architecture. Dilip Chakrabarti echoes this in his recent observation: "The ideals of ancient Indian town planning seem to run deep through the concepts embedded in the Harappan cities like Mohenjodaro and Dholavira."[66]

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