Indian Journal of Traditional Knowledge
Vol 24(5), May 2025, pp 416-431
DOI: 10.56042/ijtk.v24i5.12983

The inclusivity of system of measurement of space & proportion in *Silpa-Sastras*

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Received 19 August 2024; revised & accepted 18 January 2025

The system of measurement of space and proportion with respect to human being, *i.e.,* anthropometry, have always played a vital role in design; be it architectural design, product design, furniture design or any other design. Any design or product is considered good if it suits the user's anthropometry well. But presently, the system of measurement is fixed irrespective of the user. Through extensive literature study, it has been found that during the ancient and medieval times in India, system of measurement was derived from the user, making every product anthropometrically perfect. The instances of this are found in ancient treatises like *Manasara, Mayamatam, Vishwakarma Vastusastram, Samarangana Sutradhara, Visnudharmottara-Purana,* etc. On the other hand, in the ancient Rome, architect and military engineer Marcus Vitruvius Pollio in his book *De architectura* mentioned the perfect man of one size. Following the ideologies of Vitruvius, Italian polymath Leonardo da Vinci & Swiss-born French architect Le-Corbusier in the renaissance & modern era respectively also spoke of perfect man of one size. Da Vinci depicted it in his famous artwork The Vitruvian Man and Corbusier in his book *Le Modulor*. The main objective of this paper is to carry out a comparative study between the *Silpa-Sastras* & European system of measurement of space with respect to anthropometry. Initial findings suggest that both these systems of space measurement are derived from human dimensions and co-relate. Further, the inclusive approach of *Silpa-Sastras,* as presented in this paper, made the system of measurement and proportion more holistic in their outlook which could guide the perfect design of any entity for greater mass.

Keywords: *Angula*, Anthropometry, *Hans Purusha*, *Hasta*, *Modulor* Man, Vitruvian man

IPC Code: Int Cl.[25]: E04C 1/00, E04H 1/00

Modern age is the age of machines and mass production. Everything is modular, even the architectural components. However, these modules are used by a variety of users, largely humans. Hence it is important to understand the anthropometrics of the users. If we look at the dimensions of the human body, we find that all the dimensions are derived from a basic module, as represented in the book *Le Modulor* written by Le-Corbusier in 1948. This concept of human dimension was realized and exploited by Indian researchers/*rishis* much earlier from the Vedic period or even before. The whole system of measurement evolved from the human body. The basic unit of measurements and all others were derived from human body dimensions. This system made the entire system as user specific. While at the same time a generalized system also existed for the cases where no specific user was identified, like settlements. But the units of measurement were completely human centric and befitted human anthropometrics perfectly. Even in the west this concept of relating the measurement system with the human body was utilized much earlier. The system of measurement thus evolved was user-friendly, e.g., inch which is 1/12th part of a foot, span, cubit, yard etc. all are directly relatable to the body's dimensions. Till this system was in use, the trade was largely local as there were limitations in terms of measurements. Science and technology's growth along with global trade led to a demand for rationalization of measurements. Thus, the metric system evolved and adopted. It had a geodetic and decimal base, which completely diverged from the human dimension-based measurement system. This metric system,

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Abbreviations:
SN – *Sukraniti*; MS – *Manasara*; MM – *Mayamatam*; VV – *Viswakarmavastusastram*; RV – *Rajavallabhavastusastram*; SS – *Samarangana-Sutradhara*; MC – *Manushyalayachandrika*; CS – *Chitra Sutra* of *Visnudharmottara-Purana*.

which is currently in use, is known as SI unit system. After the invention of metric dimensions, the need for association with human body was felt again. Thus, the golden proportions and interpretation of the human body as the golden section was derived and the interrelation of human body dimensions was understood. But the basic system of measurement still remains the technology derived one. This paper here discusses different anthropometric scale of measurements of ancient India and Europe and carries out a comparative study.

Discussion on the anthropometric scale of measurements of ancient India can be found in various *Bharatiya Sastras* (Indian treatises), particularly in the *Silpa-Sastras*, the science of *Silpa* (arts and crafts)[1]. References from relevant indexed journal articles were explored to identify those *Silpa-Sastras*. Although originating from Indian traditional design methodologies, *Silpa-Sastras* have been revisited by researchers across the globe to address contemporary societal issues. A systematic literature review was undertaken using keywords such as *Vaastu-Silpa-Sastra*, *angula*, *hasta*, *vitasti*, *Hans Purusha*, *danda*, *rajju*, anthropometry, etc., to identify pertinent articles. Over 60 journal articles were identified as being related to *Silpa-Sastras*.

Research has discussed the relationship between traditional domestic architecture and the well-being of its inhabitants[2,3]. Similarly, the balance between ancient practices and the scientific rationality of *Vaastu-Purusha-Mandala* in the contemporary design of traditional domestic architecture has been highlighted[4,5]. Other studies have explored how workplaces designed in accordance with *Silpa-Sastra* principles enhance creativity and well-being for those who occupy them[6]. Additionally, the well-being of individuals residing in various building types, from sacred to secular structures, has been shown to align with the prescriptions found in *Silpa-Sastras*[7]. Further work has explained that holistic building design can be effectively achieved through the application of the *Aya* formula as outlined in *Silpa-Sastras*[8]. It has also been noted that there is a growing trend in *vaastu*-compliant designs of multistorey buildings for the elite and middle-class sectors, which has led to emerging tensions between traditional architectural ideals and contemporary urban and cultural settings[9]. Furthermore, based on theoretical frameworks from *Silpa-Sastras*, it has been argued that urban settlements-ranging from large-scale cities to small-scale homes-can be designed using the principles of *Vaastu-Silpa-Sastras*, emphasizing cultural, spatial, and environmental relevance[10-12]. Studies have also examined how *vaastu*-compliant urban configurations are influencing towns and cities both socio-culturally[13] and socio-economically[14], with these impacts being quantitatively validated through space syntax analysis[15]. Cultural tourism has likewise benefited positively from *vaastu*-oriented temple town designs[16]. Contemporary Indian temples are reportedly being constructed[17,18], and older temples reconstructed[19], with minimal disruption-thanks to the adaptable nature of the traditional knowledge systems embedded in *Silpa-Sastra*. Other scholarly works have examined how traditional Indian craftsmanship, deeply rooted in cultural identity, spirituality[1,20], and the prosperity of historical kingdoms[21], continues to be shaped by the practical applications of *Silpa-Sastras*. From ancient times to the present day, this Hindu architectural practice has flourished and evolved contextually[22] throughout South Asia[23]. Modern applications of Green Building Concepts in accordance with *Vaastu-Silpa-Sastra* principles[24], combined with the integration of natural landscapes[25], have been shown to enhance environmental harmony between human settlements and cultural heritage in the face of modern urban sustainability challenges[26]. These themes represent important domains of investigation within the traditional knowledge systems of *Silpa-Sastra*, which continue to be explored by researchers.

There are only a few journal articles that focus specifically on the systems of measurement in *Silpa-Sastra*, with four such articles identified thus far. Among them, three have examined aspects such as measurement, proportion, orientation, and aesthetic balance in both secular[27] and sacred[28] structures, as well as the relevance of ergonomics[29] in contemporary design contexts. One article, after analysing the cumulative lengths of various body parts as mentioned in an unpublished Hindi source on idol design titled- *Nakśā yād dāst pratimā ke pramān kā*, found that the total length of an image, sculpture, or idol equates to 108 *angulas*. This corresponds with the height of *Hans Purusha* described in the *Visnudharmottara-Purana* and aligns with the *Nava-tala* type from the *Talamana* system of measurement detailed in the *Brhat Samhita*[30]. Current research trends within this domain of traditional knowledge are also evident in a number of books. One publication from 2021, titled 'Fluid', compares Vitruvius' *De Architectura*'s perfect man with Leonardo da Vinci's Vitruvian Man and the *Hans Purusha* of the *Visnudharmottara-Purana*[31]. Another relevant book, published in 1997 by the National Institute of Design, Ahmedabad, is titled-'Indian Anthropometric Dimensions for Ergonomic Design Practice'. However, this text does not incorporate anthropometric principles as defined in the *Silpa-Sastras*, the classical Indian design treatises[32]. Similarly, two books-'Hindu Architecture in India and Abroad' (1946) and 'Indian Architecture According to *Manasara-Silpasastra*' (1927)-offer comparative analysis between the *Manasara* and Vitruvius' *De Architectura*, though they do not provide a detailed comparison of measurement systems in relation to anthropometry[33,34]. In order to bridge this gap in the literature, a comparative analysis of various *Sanskrit* texts pertaining to *Silpa-Sastras* and European design sources that discuss the measurement of space in relation to anthropometry has been undertaken.

Methodology

The main objective of this paper is to carry out a comparative study between the ancient Indian & European system of measurement of space with respect to anthropometry. After basic literature study from the above mentioned 30 journal articles, 55 number of *Bharatiya Sastras* were found cited in their reference sections. Out of these 55 *Bharatiya Sastras*, 9 *Sanskrit* source texts of *Silpa-Sastras* was identified which are mostly cited in those articles. From these 9 *Silpa-Sastras*, 6 *Silpa-Sastras* were selected which have exhaustive discussion on measurement system with respect to anthropometry. They are *Manasara, Mayamatam, Rajavallabhavastusastram, Samarangana Sutradhara, Manushyalayachandrika, Chitra Sutra of Visnudharmottara-Purana.* One less cited *Silpa-Sastra* namely *Viswakarmavastusastram* was selected from the above mentioned 55 *Bharatiya Sastras*, since it has broader discussion on measurement system with respect to anthropometry. As the paper mainly deals with the system of measurement of space with respect to anthropometry, the *adhyayas* (chapters) along with the *slokas* (verses) in *Silpa-Sastras*, mentioning such was identified and prescriptions (data) from those texts were collected in detail. On the other hand, system of measurement of space with respect to anthropometry from European sources on art and architecture were reviewed from the works of Vitruvius' *De Architectura*, Leonardo da Vinci's *Vitruvian Man*, and Le Corbusier's *Le Modulor*. These are considered as the seminal works in the ancient, renaissance, and modern period of Europe respectively, on the system of measurement of space with respect to anthropometry. Measurement related data were collected from these sources and analysed comparatively with the ones from the source texts of selected *Silpa-Sastras*. The results obtained after comparative analysis are discussed taking into consideration the inclusivity of system of measurement of space in *Silpa-Sastras* (Fig. 1).

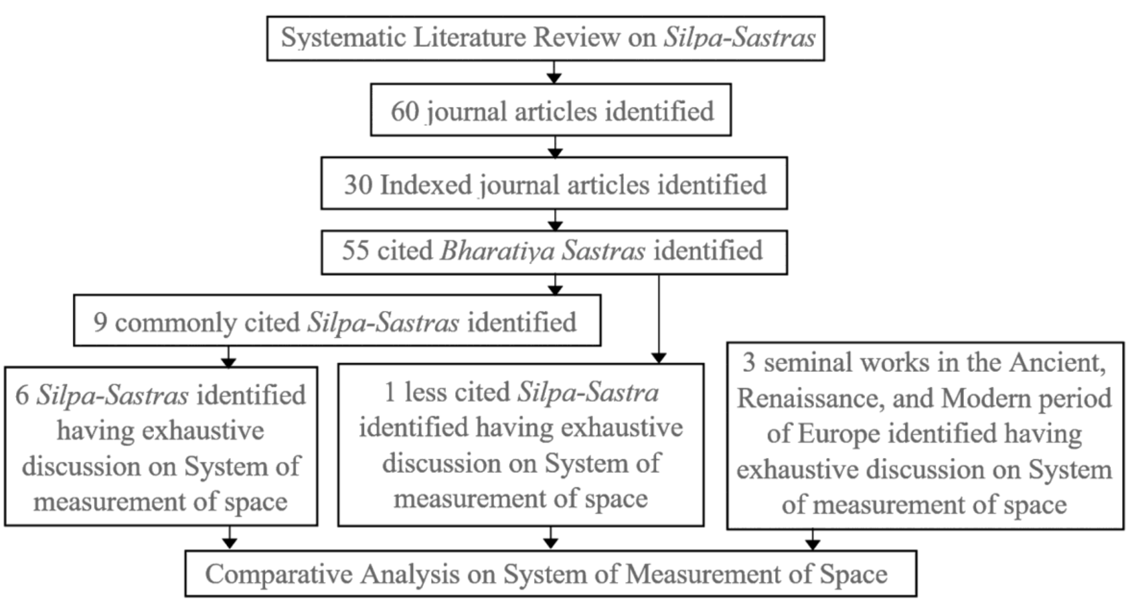

Fig. 1 — Methodology

Literature study

Silpa-Sastra

प्रासादप्रतिमारामगृहवाप्यादिसत्कृतिः।

कथितायत्रतच्छिल्पशास्त्रमुक्तंमहर्षिभिः ॥[35]– SN 4-299.

According to *Rishi* (Sage) *Sukracharya*, *Silpa-Sastra* is 'the science which deals with the rules for the construction of palaces, images, parks, houses, canals, and other good works. Thus, *Silpa-Sastras* are the scientific treatises (*Sastras*) of art (*Silpa*). Moreover, Prof. Phanindra Nath Bose in his book 'Principles of Indian *Silpasastra*: With the Text of *Mayasastra*' mentions that the literatures on *Silpa-Sastra* came into existence in the post *Gupta* period (from 6th century A.D.) when 'there was an appreciable decline in the quality of Indian Art'. During that period, the *Silpins* (artists) of inferior calibre were unable to create any artwork that could compare to the *Gupta* period or before, in terms of beauty, tranquillity, and contemplation. These *Silpa* canons became important to direct the *Silpins* in producing artworks adding rich embellishment. *Silpacharyas* (great teachers of the arts) recorded the previously practiced artistic essence of the greatest *Silpins* and transmitted them as *Silpa* maxims for future generations[36]. In these treatises, along with the other *adhyayas* (chapters) on art and architecture 'System of Measurement of Space' is an important *adhyaya.* Taking into consideration of anthropometry, system of measurement of space has been reviewed. Chapters from seven selected *Silpa-Sastras* are compared here with three selected works on art and architecture of Europe. Following section presents the literature from these texts.

The system of measurement of space as discussed in *Silpa-Sastras*

Manasara

Region: South India[37].

Author: *Rishi Manasaras*[38].

Year: 450-550 CE[39,3].

Manasara's second part of Chapter 2 elaborates on 'The System of Measurement' which is named as *Manopakarana-vidhana*[40].

Verses: MS 2-(20-29).

The unit of measurement mentioned as *angula* in this text are distinguished into 3 types. The largest one (middle finger) is made of 8 *yavas*, the intermediate one (index finger) is made of 7 *yavas*, and the smallest one (little finger) is made of 6 *yavas*. Moreover, the four different kinds of cubits (*hasta*) mentioned above in the text are used to measure different entities. Conveyances (*yana*) and couches/furniture (*sayana*) to be measured in the *kishku-hasta.* Mansions (*vimana*) to be measured in the *prajapatya-hasta.* Edifices/buildings (*vastu*) to be measured in the *dhanurmushti-hasta.* Villages and towns to be measured in the *dhanurgraha-hasta* Moreover, in general, *kishku-hasta* may also be used in measuring all these objects too.

The system of measurement of space as mentioned in *Manasara*:

8 *paramanus* (atoms) =	1 *rathadhuli* (car dust)
8 *rathadhulis* =	1 *balagra* (hair's end)
8 *balagras* =	1 *liksha* (nit)
8 *likshas* =	1 *yuka* (louse)
8 *yukas*=	1 *yava* (barley grain)
8 *yavas* =	1*angula* (finger's breadth)
12 *angulas* =	1 *vitasti* (span)
2 *vitastis* or 24 *angulas* =	1 *kishku-hasta* (small cubit)
25 *angulas* =	1 *prajapatya-hasta* (medium cubit)
26 *angulas* =	1 *dhanurmushti-hasta* (large cubit)
27 *angulas* =	1 *dhanurgraha-hasta* (largest cubit)
4 *dhanurmushti-hastas* =	1 *danda* (rod)
8 *dandas* =	1 *rajju* (rope)

Mayamatam

Region: South India[41].

Author: Architect *Maya*[42].

Year: 11th – 12th century CE[23,30].

Mayamatam's first part of Chapter 5 elaborates on The System of Measurement which is named as *Manopakaranam*[43].

Verses: MM 5-(1-12).

The smallest unit of measurement is mentioned as *paramanu* or atom which can be perceived by the vision of a *yogi* (who have mastered their senses). The four different kinds of cubits (*hasta*), mentioned above, are used to measure different entities. Vehicles (*yana*) and couches/furniture (*sayana*) to be measured in the *kishku-hasta.* Mansions (*vimana*) to be measured in the *prajapatya-hasta.* Edifices/buildings (*vastu*) to be measured in the *dhanurmushti-hasta.* Villages and towns to be measured in the *dhanurgraha-hasta*. *Kishku-hasta* can also be used in measuring all other different buildings. Moreover, villages, *pattana*, towns, *nigama*, *kheta*, palaces, etc. are to be measured in *yasti*. Houses are to be measured in *hasta*. Vehicles and couches/furniture are to be measured in *vitasti*. Small objects are to be measured in *angula*. Very small objects are to be measured in *yava*.

In this text three different kinds of *angulas* are mentioned which are *Manangula*, *Matrangula* and *Dehalabdhangula*. *Manangula* is the middle finger's breadth, *Matrangula* is the length of middle phalanx of the middle finger or the thumb of the owner or of the *Sthapati*. *Dehalabdhangula* (measurement taken from a specific body) is often defined as an iconometric relative unit used in idols and sacrifices, etc.

The system of measurement of space as mentioned in *Mayamatam*:

8 *paramanus* (atoms) =	1 *ratharenu* (car dust)
8 *ratharenus* =	1 *valagra* (hair's end)
8 *valagras* =	1 *liksha* (nit)
8 *likshas* =	1 *yuka* (louse)
8 *yukas*=	1 *yava* (barley grain)
8 *yavas* =	1 *angula* / *manangula* (finger's breadth)
12 *angulas* =	1 *vitasti* (span)
2 *vitastis* or 24 *angulas* =	1 *kishku-hasta* (small cubit)
25 *angulas* =	1 *prajapatya-hasta* (medium cubit)
26 *angulas* =	1 *dhanurmushti-hasta* (large cubit)
27 *angulas* =	1 *dhanurgraha-hasta* (largest cubit)
4 *hasta* =	1 *yasti* (pole)
8 *yastis* =	1 *rajju* (rope)

Viswakarma Vastusastram

Region: North India.

Author: Architect *Viswakarma.*

Viswakarma Vastusastram's Chapter 7 elaborates on Units of Measurement which is named as *Manakathanam*[44].

Verses: VV 7-(72-84).

This text begins the unit with the longest variety of paddy, *Sali Vrihi*. Units smaller than this are mentioned for academic purpose only. *Paramanu* (atom)is the smallest unit. Idols are generally measured in the unit of *Dhanurmusti* or yard. *Hasta* or cubit is used for the measurement of canopy (*Vimana*), pedestals for idols and sacrificial halls. *Danda* or small rod is used for measuring villages and *Raja Danda* or the royal rod is used for measuring cities. Moreover, *Danda* or *Raja Danda* is used for measuring other places like roads or fields. Villages, hills, forests, tanks and palaces are measured by the prescribed *Raja Danda*. *Brahma Danda* is used for measuring temple sites and halls.

The system of measurement of space as mentioned in *Viswakarma Vastusastram*:

3 *vrihis* (paddy grain) =	1 *angula* (finger's breadth)
12 *angulas* =	1 *vitasti* (span)
2 *vitastis* =	1 *hasta* (cubit)
2 *hastas* =	1 *dhanurmusti* (yard)
2 *dhanurmustis* =	1 *danda* (small rod)
2 *dandas* =	1 *raja danda* (royal rod)
2 *raja dandas* =	1 *brahma danda* (sacred rod)

Rajavallabhavastusastram

Region: Mewar (North-western India – present Rajasthan, Gujarat)[45].

Author: *Sutradhara Mandana*[45].

Year: During the rule of Maharana Kumbha (1433-1468 CE)[46].

Rajavallabhavastusastram's Chapter 1 (*Misrokolakshanam*) describe units of measurement of space in *Hastaprakalpanam* to *Maan-Nirdharanam*[47].

Verses: RV 1-(33-36) & RV 1-39.

In this text the smaller dimension is up to *angula* measurement and the types of *angula* are same here. There is slight variation in the larger dimensions from the other texts. *Uttama* or *Jyestha Gaja* (with 8 barley grains placed side by side for a *Matra*) is used to measure villages and cities along with the miles or *yojana*, etc. *Madhyama Gaja* (with 7 barley grains placed side by side for a *Matra)* is used to measure palaces of the kings, temples and the idol houses. *Laghu Gaja* (with 6 barley grains placed side by side for a *Matra)* is used to measure carts, bed, umbrella, seats and the weapons. The design of the *Gaja*/scale is described by the following *slokas* (verses) (Fig. 2).

The system of measurement of space as mentioned in *Rajavallabhavastusastram*

12 *matras* / *angulas* =	1 *tala* (span of a hand)
2 *talas* (24 *angulas*) =	1 *gaja / hasta* (cubit)
1 ¾ *gaja* (42 *angulas*) =	1 *kishku*
4 *gajas* (96 *angulas*) =	1 *danda* (rod)
2000 *dandas* =	1 *krosa*
2 *krosas* =	1 *gavyuti*
2 *gavyutis* =	1 *yojana* (miles)
100 *yojanas* =	1 *koti*

Samarangana Sutradhara

Region: Malwa[48], in Madhya Pradesh, India.

Author: King Bhoja of Dhara of the Paramara dynasty[49].

Year: First part of 11th century CE[48].

Chapter 9 of *Samarangana Sutradhara* takes into account the system of measurement of space. The chapter is named as *Hastalaksana*[50].

Verses: SS 9-(39-47) & SS 9-(4-14).

This treatise has a different nomenclature for the basic dimensioning than the previous mentioned texts. Like the other treatises relation of *angula* with *vitasti* comes to the same size but the relation with *danda, krosa, gavyuti* and *yojana* are slightly different. The above-mentioned verses also describe the marking of a one *hasta* long scale. The scale is said to be of 1, 1 ½, or 2 *angula* wide and ½ *angula* thick made from some specific wood. It is divided into 8 equal parts of three *angula* each called *parva*. 4 *parva* are kept as such with making of flowers on the marking. From the center, the *angula* marking is divided into two parts, the eighth *angula* marking into 3 parts and twelfth into 4 parts. Every *parva* marking is to be ornamented with a flower (Fig. 2).

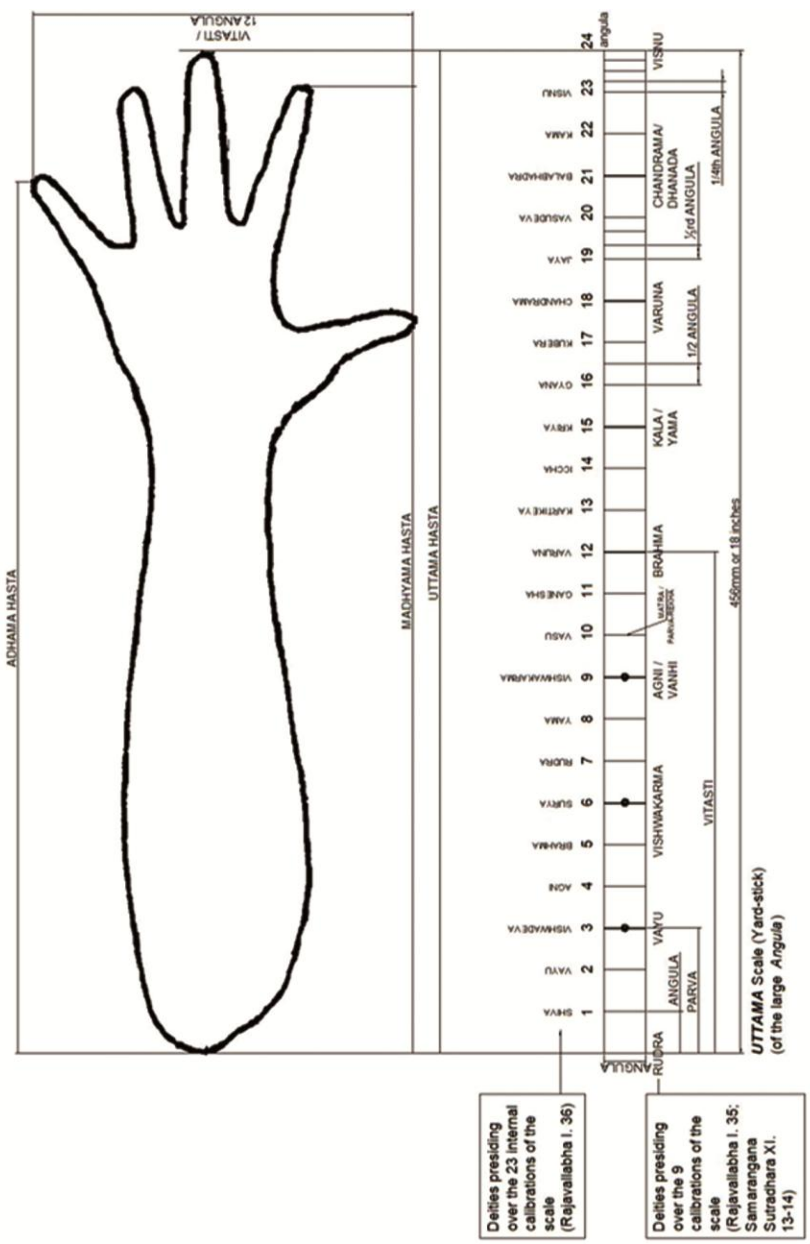

Fig. 2 — *Uttama* scale [yardstick of the large *angula*] (Source: Authors, after *Samarangana Sutradhara* & Rajavallabhavastusastram)

The system of measurement of space as mentioned in *Samarangana Sutradhara*

1 *angula* =	*matra*	14 *anugla* =	*anaha-pada*
2 *angula* =	*kala*	21 *angula* =	*ratni*
3 *angula* =	*parva*	24 *angula* =	*aratni*
4 *angula* =	*mushti*	42 *angula* =	*kishku*
5 *angula* =	*tala*	84 *angula* =	*vyama / purusha* (height of a man)
6 *angula* =	*kara pada*	96 *angula* =	*dhanush* (bow)
7 *angula* =	*drishti*	106 *angula* =	*danda* (rod)
8 *angula* =	*tuni*	3 *danda* =	1 *nalva*
9 *angula* =	*pradesa*	1000 *danda* =	1 *krosa*
10 *angula* =	*saya tala*	2 *kros* =	1 *gavyuti*
11 *angula* =	*go-karna*	4 *gavyuti* =	1 *yojana*
12 *angula* =	*vitasti* (span of a hand)	8000 *danda* =	1 *yojana*

Manushyalayachandrika

Region: Kerala[51], India.

Author: Neelakanthan Musat[52].

Year: After the early part of 15th century CE[51].

Manushyalayachandrika text's Chapter 3, *Manbhedyonyayavyadinirnay* discusses on the system of measurement of space[53].

Verses: MC 3-(1-4) & MC 3-(9-14).

In spite of having different nomenclature for the basic dimensioning than the previous mentioned texts, the relations among the units of measurement are same as the other South Indian *Silpa-Sastras* – *Manasara* & *Mayamatam*. In this text 8 types of cubits have been discussed. For measuring high rise structures (*Vimana*) & temples (*Devgriha*) *prajapatya* cubit is required to be used. For all other kinds of buildings, *dhanurmushti* cubit to be used. For measuring villages, *dhanurgraha* cubit is mentioned to be used.

The system of measurement of space as mentioned in *Manushyalayachandrika*

8 *tila* (sesame seed) =	1 *yavodar* (thickness of barley grain)
8 *yavodar*=	1 *matrangula* (length of finger's phalanx)
12 *matrangula*=	1*vitasti* (span of hand)
24 *matrangula*=	1 *kar / kishku / aratni / bhuja / dor / mushti* (small cubit)
25 *matrangula*=	1 *prajapatya* (medium cubit)
26 *matrangula*=	1 *dhanurmushti* (large cubit)
27 *matrangula*=	1 *dhanurgraha* (largest cubit)
28 *matrangula*=	1 *prachya*
29 *matrangula*=	1 *vaideh*
30 *matrangula*=	1 *vaipulya*
31 *matrangula*=	1 *prakirna*

The different types of finger's length as mentioned in *Manushyalayachandrika*

8 *yavodars* (lateral widthof barley corn's middle portion) =	1*varisthmatrangula* (middle finger's length of phalanx)
7 *yavodars*=	1 *madhyammatrangula* (index finger's length of phalanx)
6 *yavodars* =	1 *adhamamatrangula* (small finger's length of phalanx)

Chitra Sutra* of *Visnudharmottara-Purana

It is one of the oldest known complete *Sanskrit* treatises on fine arts in India. *Chitra Sutra*, Part 3 of *Visnudharmottara-Purana* begins with *Rishi Markandeya's* explanation of the integrative nature of all disciplines and in turn the universe to King *Vajra*.

Verses: CS 35-(8-11) & CS 37-(1-4).

In Chapter 35, *Avamocchrayamana*[54], of *Visnudharmottara-Purana*, *Rishi Markandeya* mentions five kinds of perfect men having varied heights with different body proportions. As a basis of measurement 12 *Angulas* = 1 *Tala* (span of hand). According to *Rishi Markandeya*, out of these five men, the proportions of *Hans* are said to be nearer to perfection. *Hans*, in *Sanskrit* stands for a mythical bird that is the finest among all birds. The *Hans* bird that appears closest to a swan in its physical appearance is said to have the ability of separating divine nectar (*amrit*) from water.

In this treatise, along with the 5 types of perfect men, 5 types of perfect women's measurements are also mentioned in Chapter 37, *Samanva mana*[55]. As an instance, from Verses 1 to 4, *Hans Stree* (Woman)'s waist has to be 2 fingers thinner than that of *Hans Purusha* (Man), whereas her hip has to be 4 fingers wider.

In Chapter 36, *Pramanadhyaya*[56], *Rishi Markandeya* begins his detailed discourse on the proportions of human body. One of the key reasons why *Markandeya's* text could achieve greater depth with his calculations is simply mathematical. The advantage of using a measuring unit as small as the finger gives *Markandeya* the freedom to provide measurements of even body parts such as teeth, eyes and even nails. For instance, according to *Markandeya*, the front teeth of a perfect man are half *angula* in length.

Five kinds of perfect men as mentioned in *Chitra Sutra* of *Visnudharmottara-Purana*

Hans =	108 *Angulas* (100+8)
Bhadra =	106 *Angulas* (100+6)
Malvya =	104 *Angulas* (100+4)
Ruchak =	100 *Angulas*
Shashak =	90 *Angulas* (100-10)

Prof. Prasanna Kumar Acharya is renowned for his exhaustive research work on *Manasara Silpa-Sastra*. After researching on *Manasara* along with other several *Silpa-Sastras* he derived the value of an *angula* which is 'three-fourths of an inch'[57].

The system of measurement of space according to European design perspectives

***De architectura* (*On architecture*)**

Vitruvius, who is often called the first architect of the world, is famous for his pioneering text on architecture, *De architectura* – the only surviving book from the ancient Roman period on architecture, which was eventually rediscovered in the 15th century. *De architectura,* considered to be written around 15-30 BC, comprises of ten brief books containing principles of building design and town planning, including city drainage and water systems. In Book III, Chapter 1, Symmetry: In Temples and The Human Body of *De architectura*, a perfect man's proportions have been elaborated by Vitruvius.

According to Vitruvius, the navel of such a man is at the centre of his body, and if a circle is drawn from this centre with the arms and legs stretched, the tips of the fingers and toes would touch the circumference of the circle. Moreover, if a square is drawn, they would touch the boundaries of the square too. In fact, once extended fully, the length of the stretched arms is equal to the height of a perfectly proportionate man. According to Vitruvius this length is equivalent to ten heads when the head is measured 'from the chin to the top of the forehead and the lowest root of the hair' (Fig. 3).

In this book, Vitruvius moreover mentioned that a man's height is six times of his foot. The height of the body as expressed in number of feet being limited to six, they held that this was the perfect number and observed that the cubit consisted of 6 palms or of 24 fingers[58].

Vitruvius' verbatim in *De architectura*

4 fingers =	1 palm
4 palms =	1 foot
6 palms =	1 cubit
4 cubits =	1 man's height
4 cubits =	1 footstep
24 palms =	1 man's height
The length of the outspread arms =	1 man's height
1 Head =	1/10th of man's height

The Vitruvian Man

The *Vitruvian Man* is considered to be the ultimate symbolic representation of the Renaissance period and one of the finest handworks of Leonardo da Vinci created around 1490. The drawing is a beautiful convergence of artistic, scientific and mathematical knowledge. The Vitruvian Man basically represents a perfect physically proportionate man (Fig. 4).

The idea of the Vitruvian Man came to da Vinci's mind from a Roman architect and engineer of 1st century BC. He was Marcus Vitruvius Pollio who described the anthropometry of a perfectly proportionate man. The drawing was named after Vitruvius by Leonardo, as he was reproducing the proportions given by the Roman. It is to be taken into account that da Vinci did not entirely follow the proportions given by Vitruvius while creating The Vitruvian man. Out of roughly around 22 measurements noted by Vitruvius, Leonardo da Vinci

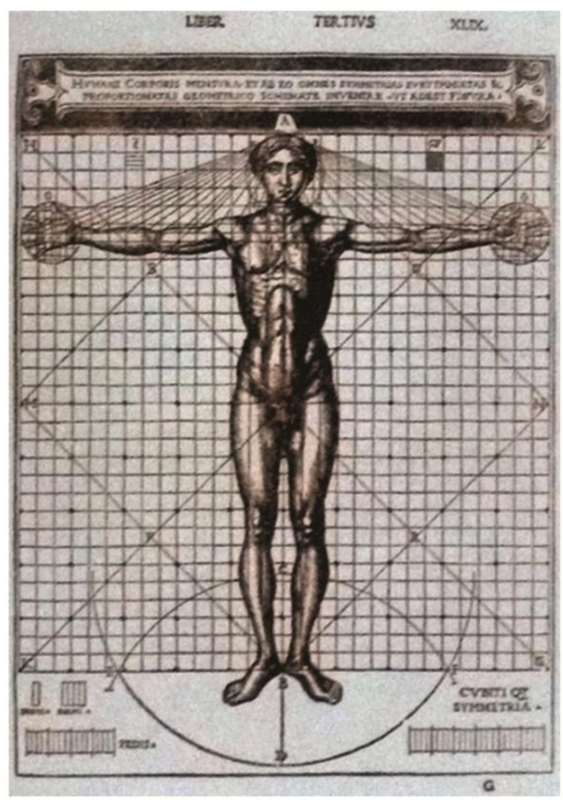

Fig. 3 — *Vitruvius' Perfect Man*, illustration in the edition of *De architectura* by Vitruvius; illustrated edition by Cesare Cesariano (1521)[59]

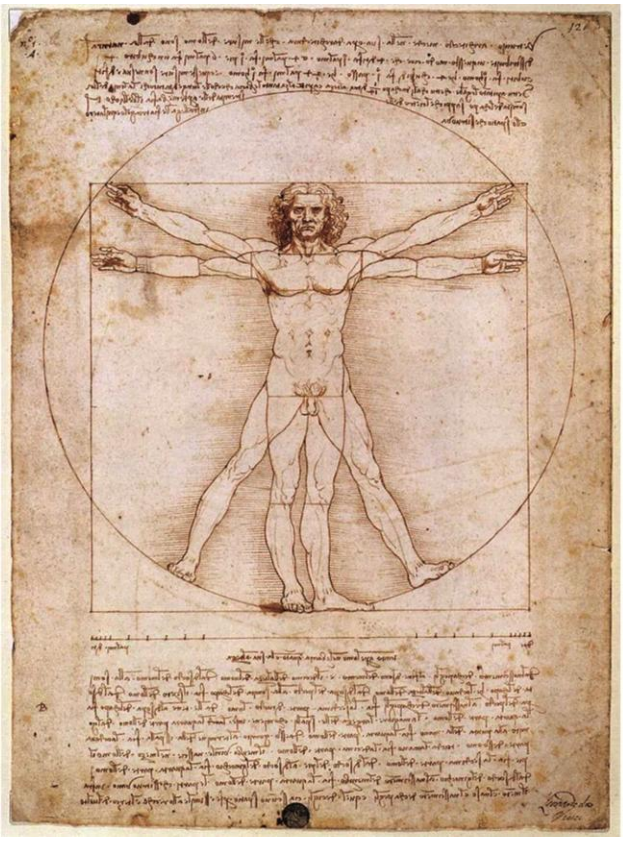

Fig. 4 — Leonardo da Vinci's *The Vitruvian Man*[61]

takes only less than half and combines them with his self-devised specifications of human physical proportions to create the iconic image. In the upper part of the image, da Vinci mentioned the anthropometric proportion of Vitruvius verbatim written in *De architectura*. In the lower part of the image da Vinci mentioned his own modified way of anthropometric proportion. The distances from the chin to the nose and the hairline and the eyebrows are equal to the ears and one-third of the face[60].

Leonardo da Vinci's verbatim in *The Vitruvian Man*:

From below the chin to the top of the head =	$1/8^{th}$ of man's height
From above the chest to the top of the head =	$1/6^{th}$ of man's height
From above the chest to the hairline =	$1/7^{th}$ of man's height
From the chest to the head =	$1/4^{th}$ of man's height
The maximum width of the shoulders =	$1/4^{th}$ of man's height
From the elbow to the tip of the hand =	$1/4^{th}$ of man's height
The distance from the elbow to the armpit =	$1/8^{th}$ of man's height
The length of the hand =	$1/10^{th}$ of man's height
The foot =	$1/7^{th}$ of man's height
From below the foot to below the knee =	$1/4^{th}$ of man's height
From below the knee to the root of the member =	$1/4^{th}$ of man's height

Le Modulor

The Swiss born French architect Le Corbusier (1887-1965) devised the anthropometric scale of proportions, *Le Modulor*. The Anglo-Saxon foot and inch and the international metric system got united by the introduction of Le Corbusier's scale of visual measures, *Le Modulor*. While he was fascinated by ancient civilisations' measuring systems linked to the human body: elbow (cubit), finger (digit), thumb (inch) etc., metric system used to trouble him, which was introduced to the society during his time of practicing architecture.

Height of a man with his arm raised is the basis of this anthropometric scale. 1.75 m is considered as the standard human height, without taking into consideration the feminine measurement. Refining the dimensions overall height of the *Modulor* with raised arm is set at 2.26 m (Fig. 5).

Several Le Corbusier's buildings used this system of measurement and later this got codified into two books *Le Modulor* in 1948 and *Modulor* 2 in 1955.

Le Corbusier developed the *Modulor* taking inspiration from Vitruvius' *De architectura* & Leonardo's *The Vitruvian Man.* Both masterpieces helped him to discover mathematical proportions in the human body. He then used that knowledge for improving the appearance and function of architecture. The golden ratio, the Fibonacci numbers, human measurements, and the double unit are the basis of this system of measurement.

A French man's height of 1.75 metres, *i.e.,* 5 ft 9 in, was the basis of the Modular Man's height, initially. In 1946 this value was changed to 1.83 metres because "in English detective novels, the good-looking men, such as policemen, are always six feet tall!". Thus, the overall height of the raised arm man got set at 2.262 m.

Le Modulor is represented graphically as a stylized human figure with one arm raised standing next to two vertical measurements:

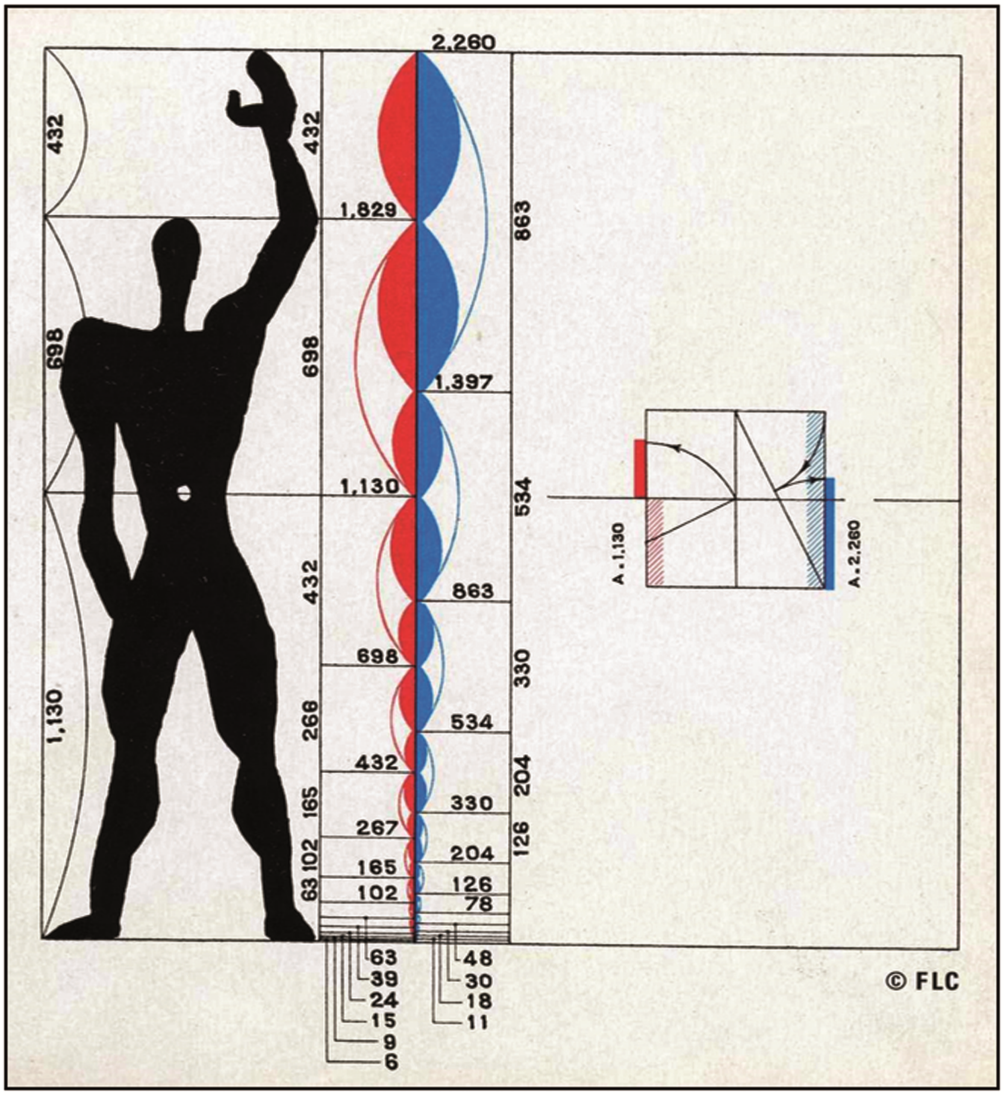

Fig. 5 — *The Modulor*, based on the Fibonacci sequence and the Golden Section[63]

- Figure's navel height is the basis of the red series, *i.e.*, in the original version 1.08 m and in the revised version 1.13 m, then segmented according to Phi.
- Figure's entire height is the basis of the blue series, double the navel height, *i.e.*, in the original version 2.16 m and in the revised version 2.26 m, then segmented similarly[62].

Results and Discussion

From the Table 1 below we could find that there are certain common basic units which are mentioned in several *Silpa-Sastras*:

Paramanu, rathadhuli/rathrenu, valagra, liksha, yuka, yava, angula/matra, vitasti/tala, kishku-hasta, prajapatya-hasta, dhanurmusti-hasta, dhanurgraha-hasta, danda, rajju, krosa, gavyuti, yojana are some of the basic units of system of measurement of space which are common in the selected *Silpa-Sastra* treatises of different regions of India. Relation between these units along with the category of scales and their uses are tabulated below.

(i) From Table 2 we could find that the scales are ranging from nano level to macro level. Scales of micro, architecture and macro levels are tangible, on the other hand nano level scales are intangible in nature. Minute intricate detail work of ornaments and jewellery requires micro level scales for measurement. Designing of furniture, weapons, sculptural work along with architectural work requires architectural scale for their measurement. Village, town and city planning requires both architectural and macro level scales for their measurement.

Table 1 — Summary of the units of measurement of space according to the selected *Silpa-Sastras.*

Units of measurement of space in the selected *Silpa-Sastras*		Selected *Silpa-Sastras*						
		MS	MM	VV	RV	SS	MC	CS
paramanu	atom	●	●	-	-	-	-	-
rathadhuli	speck of dust	●	-	-	-	-	-	-
ratharenu		-	●	-	-	-	-	-
valagra	tip of hair	●	●	-	-	-	-	-
liksha	nit	●	●	-	-	-	-	-
yuka	louse	●	●	-	-	-	-	-
tila	sesame seed	-	-	-	-	-	●	-
yava	barley grain	●	●	-	-	-	-	-
yavodar	thickness of barley grain	-	-	-	-	-	●	-
vrihi	paddy grain	-	-	●	-	-	-	-
angula	finger	●	●	●	-	●	-	●
matra		-	-	-	●	●	-	-
manangula	middle finger's breadth	-	●	-	-	-	-	-
matrangula	length of middle finger's phalanx	-	●	-	-	-	●	-
dehlabhdhangula	-	-	●	-	-	-	-	-
kala	-	-	-	-	-	●	-	-
parvan	-	-	-	-	-	●	-	-
mushti	-	-	-	-	-	●	-	-
tala	-	-	-	-	-	●	-	-
kara pada	-	-	-	-	-	●	-	-
drishti	-	-	-	-	-	●	-	-
tuni	-	-	-	-	-	●	-	-
pradesa	-	-	-	-	-	●	-	-
saya tala	-	-	-	-	-	●	-	-
go-karna	-	-	-	-	-	●	-	-
vitasti	span of hand	●	●	●	-	●	●	-
tala		-	-	-	●	-	-	●
anaha-pada	-	-	-	-	-	●	-	-
ratni	-	-	-	-	-	●	-	-
aratni	-	-	-	-	-	●	-	-
kar	small cubit	-	-	-	-	-	●	-
aratni		-	-	-	-	-	●	-
bhuja		-	-	-	-	-	●	-
dor		-	-	-	-	-	●	-
mushti		-	-	-	-	-	●	-
hasta		-	-	●	-	-	-	-
gaja		-	-	-	●	-	-	-
kishku-hasta / kishku		●	●	-	●	●	●	-
prajapatya-hasta / prajapatya	medium cubit	●	●	-	-	-	●	-
dhanurmusti-hasta / dhanurmusti	large cubit	●	●	-	-	-	●	-
dhanurgraha-hasta / dhanurgraha	largest cubit	●	●	-	-	-	●	-
prachya	-	-	-	-	-	-	●	-
vaideh	-	-	-	-	-	-	●	-
vaipulya	-	-	-	-	-	-	●	-
prakirna	-	-	-	-	-	-	●	-
dhanurmusti	yard	-	-	●	-	-	-	-
purusha	height of man	-	-	-	-	●	-	-
dhanush	bow	-	-	-	-	●	-	-
danda	pole / rod	●	-	●	●	●	-	-
yasti		-	●	-	-	-	-	-
raja danda	royal rod	-	-	●	-	-	-	-
brahma danda	sacred rod	-	-	●	-	-	-	-
nalva	-	-	-	-	-	●	-	-
rajju	rope	●	●	-	-	-	-	-
krosa	-	-	-	-	●	●	-	-
gavyuti	-	-	-	-	●	●	-	-
yojana	miles	-	-	-	●	●	-	-
koti	-	-	-	-	●	-	-	-

Table 2 — Basic units of system of measurement of space common in the selected *Silpa-Sastras.*

System of measurement of space		Type of scale	Used to measure
8 *paramanu* (atoms) =	1 *rathadhuli / ratharenu* (speck of dust)	Nano scale	-
8 *rathadhuli / ratharenu* (specks of dust) =	1 *valagra* (tip of hair)		
8 *valagra* (tips of hair) =	1 *liksha* (nit)	Micro scale	Jewellery, ornaments
8 *liksha* (nits) =	1 *yuka* (louse)		
8 *yuka* (lice) =	1 *yava* (grain of barley)		
8 *yava* (grains of barley) =	1 *angula* (finger)	Architectural scale	Sculpture, furniture, conveyances, weapons
12 *angula* (fingers) =	1 *vitasti / tala* (span of hand)		
2 *vitasti / tala* (spans of hand) or 24 *angula* (fingers) =	1 *kishku-hasta* (small cubit)		
25 *angula* (fingers) =	1 *prajapatya-hasta* (medium cubit)		Architecture
26 *angula* (fingers) =	1 *dhanurmusti-hasta* (large cubit)		
27 *angula* (fingers) =	1 *dhanurgraha-hasta* (largest cubit)		Village, town & city planning
4 *hasta* (cubits) =	1 *danda* (pole)		
8 *danda* (poles) =	1 *rajju* (rope)	Macro Scale	
2000 *danda* (poles) =	1 *krosa*		
2 *krosa* =	1 *gavyuti*		
2 *gavyuti* =	1 *yojana* (miles)		

(ii) For measurement of different entities, different *hastas* are being used. With the change in *hastas,* number of *angulas* also change simultaneously. There are three *pramanas* (measurements) of *angulas* 6 *yava*, 7 *yava* & 8 *yava*. *Adhama angula* (little finger) is the basis of *kishku hasta* scale, *uttama angula* (middle finger) is the basis of *dhanurgraha-hasta* scale. This concept of scale eventually provides offsets in whatever are being designed with the help of different scales.

(iii) In the *Silpa-Sastra* treatises anthropometric scale's range of units are coming from human measurements. As the treatises are from different regions of India, taking into consideration the context of different places, certain similar units' names and proportions are varying. For example, in most south Indian treatises (like *Manasara, Mayamatam, Manushyalayachandrika*) it is found that 24 *angulas* = 1 *kishku-hasta* but in the treatises from Malwa (*Samarangana Sutradhara*) & Mewar (*Rajavallabhavastusastram*) 42 *angulas* = 1 *kishku.* This happens because *Silpa-Sastras* were contextually written by the *Silpacharyas* according to different geographic regions where the body proportions of human beings' changes.

(iv) The discussion of different types of *purusha* in *Chitra Sutra* of *Visnudharmottara-Purana* is a confirmation of acceptability of variations of proportions in the anthropometric scales.

Using the derivation of an *angula* (Fig. 6) which is ¾"[57] mathematical relations on anthropometric measurement are prepared below:

Anthropometric measurement in *Silpa-Sastras*, mapped to contemporary measurement units:

8 grains of barley = 1 *Angula* = ¾".

Therefore,

Height of *Hans Purusha* =	108 *Angulas* =	108 x ¾" =	81'' =	6'9" =	2.0574 m.
Height of *Bhadra Purusha* =	106 *Angulas* =	106 x ¾" =	79.5" =	6'8" =	2.032 m.
Height of *Malvya Purusha* =	104 *Angulas* =	104 x ¾" =	78" =	6'6" =	1.9812 m.
Height of *Ruchak Purusha* =	100 *Angulas* =	100 x ¾" =	75" =	6'3" =	1.905 m.
Height of *Shashak Purusha* =	90 *Angulas* =	90 x ¾" =	67.5" =	5'8" =	1.7272 m.

Anthropometric measurement in Vitruvius' *De architectura*:

1 palm = 4 fingers.

1 cubit = 6 palms = 4 x 6 = 24 fingers.

4 cubits = 1 man's height = 24 x 4 = 96 fingers.

Now, 4 fingers = 1 palm.

Therefore, 96 fingers = 96/4 = 24 palms.

Again, 4 palms = 1 foot.

Therefore, 24 palms = 24/4 = 6 feet.

Height of Vitruvius' Perfect Man = 10 Heads or 6 feet.

Therefore, 6' = 72" = 1.8288 m = 96 fingers.

Anthropometric measurement in Leonardo da Vinci's 'The *Vitruvian Man*':

1 foot = 1/7th Height of The Vitruvian Man.

Again, 1 foot = 4 palms (*De Architectura).*

Therefore, 7 feet = 4 x 7 = 28 palms.

24 palms = 96 fingers (*De Architectura).*

Therefore, 28 palms = (96 x 24) / 28 = 112 fingers.

Height of The Vitruvian Man = 7' = 84" = 2.1336 m = 112 fingers.

Anthropometric measurement in Le Corbusier's *Le Modulor*:

Height of *Le Modulor* = 1.829 m.

1.829 m = 6' = 72" = 72 / ¾" = 96 fingers.

Comparing the anthropometric scale of the perfect men mentioned in the *Chitra Sutra* of *Visnudharmottara-Purana* with the perfect men of the three selected European sources of art and architecture we can find that the *Vitruvian Man* is the tallest among all (Table 3). The perfect man of *Silpa-Sastra* treatises, *i.e.*, *Hans Purusha*, is almost the same height that is, 1 inch shorter than the Vitruvian Man. The two other perfect men of Le Corbusier and Vitruvius are both 6 feet in height. Shortest perfect man of *Silpa-Sastra* treatises, i.e., *Shashak Purusha* (5'8"), is almost the same height of the perfect man prescribed by Le Corbusier & Vitruvius, that is, 2 inches shorter than *Le Modulor* and Vitruvius' perfect man respectively. On the other hand, the heights of three other perfect men – *Bhadra, Malvya* & *Ruchak Purusha* come within the range of the heights of three European perfect men as taken into consideration. Thus, from this discussion we can infer that European system of measurement considers only one single proportion of *Vitruvian Man* or *Le Modulor* as the perfect man. Hence, in Indian system, there are various possibilities of perfect man, that is, 5 *Purushas* of *Chitra-Sutra*.

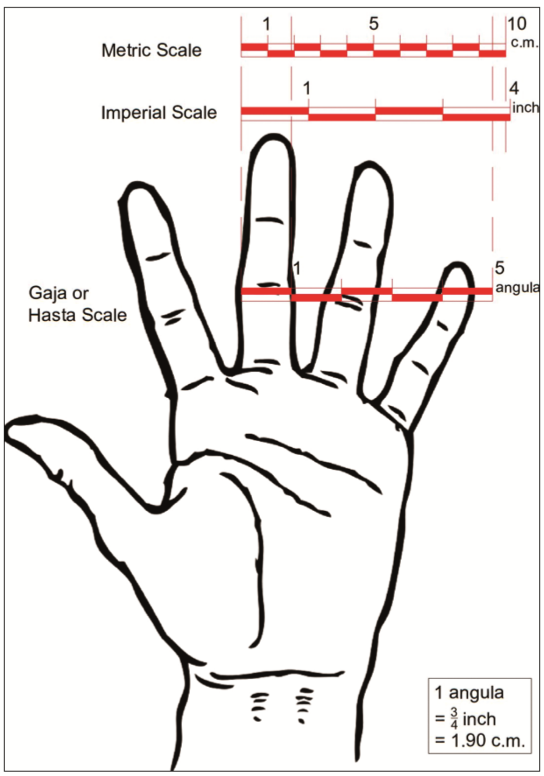

Fig. 6 Comparative Scales of Measurement of Space, (Source: Authors after P. K. Acharya[57])

Along with the comparative study done with respect to anthropometry between the seven selected *Silpa-Sastras* and three European sources on art and architecture we came up with the following inferences too:

(i) Roman Architect Vitruvius predominantly mentioned the length of the face as a unit to measure human body. On the other hand, in ancient India, *Rishi Markandeya* used a much smaller unit – the width of the middle finger. The entire human body got measured in multiples by the width of a single finger (*angula*). The applicability of smaller measuring unit gives *Markandeya* the advantage to measure smaller body parts too. This information, transferred through several *Silpa-Sastras*, that our body is proportionate to the width of a finger is simply astonishing.

(ii) Another instance that takes *Markandeya*'s explanation to a much-advanced level is his mentioning of five kinds of perfect men. Unlike Vitruvius, Leonardo da Vinci & Le Corbusier who gave the idea of proportions for only one kind, which is not practical considering the society we live.

(iii) Moreover, Vitruvius' perfect man in *De architectura*, da Vinci's *The Vitruvian Man* and Le Corbusier's *Le Modulor* are all depiction of a male body. It is often blamed as a symbol of gender bias and impractical. On the other hand, in *Visnudharmottara-Purana*, along with the five types

Table 3 — Comparative analysis of measurements for human height on anthropometric scale of proportions.

Anthropometric scale of proportions	Height in no. of fingers / *Angulas*	Height in metric scale (Metre)	Height in imperial scale (Feet & Inch)
The Vitruvian Man	112 fingers	2.1336 m	7'
Hans Purusha	108 *Angulas*	2.0574 m	6'9"
Bhadra Purusha	106 *Angulas*	2.032 m	6'8"
Malvya Purusha	104 *Angulas*	1.9812 m	6'6"
Ruchak Purusha	100 *Angulas*	1.905 m	6'3"
Le Modulor	96 fingers	1.829 m	6'
Vitruvius' Perfect Man	96 fingers	1.8288 m	6'
Shashak Purusha	90 *Angulas*	1.7272 m	5'8"

of perfect men, measurements of five types of perfect women are also given.

(iv) Leonardo da Vinci, while drawing the Vitruvian man, did not follow the words of Vitruvius verbatim. For example, the height of Vitruvian man is equivalent to the width of 112 fingers whereas the perfect man of Vitruvius and *Le Modulor* of Le Corbusier translates to be just 96 fingers tall. Thus, *Hans* Man with the height of 108 fingers is closer to Leonardo's Vitruvian man. On the other hand, *Vishnudharmottara-Purana's* five types of perfect men come under the range between 108 *angulas* and 90 *angulas* in height. Within this range the perfect man of Vitruvius and *Le Modulor* of Le Corbusier also fits with 96 fingers.

(v) Moreover, five different types of perfect men and women as mentioned in *Vishnudharmottara-Purana* will have three different types of *hasta* scales for each type and for each gender as mentioned in other *Silpa-Sastras.* This ultimately will lead into the generation of fifteen types of *hasta* scales for men and fifteen types of *hasta* scales for women, *i.e.*, thirty *hasta* scales in total. This inclusivity of anthropometric approach in *Silpa-Sastras* made the system of measurement and proportion more holistic in their outlook which ultimately will lead into designing of any entity perfect for greater mass.

Moreover, the commonality between the ancient Indian and European systems of measurement of space discussed above is that they both were derived from the human body's measurement and proportion which is termed as anthropometry. But the difference between them is that the European system speaks of only one perfect size which is not practical at all, as there will be different body types and body sizes in every geographic region of the world whose evidence we find in the sizes of clothing itself. As a matter of instance, for example, size M of a t-shirt in India is equivalent to size S of a t-shirt in Italy. On the other hand, from ancient period, *Silpins* in India used to practice art and architecture taking care of this fact that there are five different perfect men and five different perfect women. As a result of which the chapter on the 'system of measurement' mentioned in the *Silpa-Sastra* treatises, which evolved in the later period in different parts of Indian subcontinent have different proportions within the same measurement system of space. So, there was no one perfect man's concept in Indian subcontinent, rather it was varying with the geographical context, without discriminating any ethnicity and gender. This is the impactful difference with holistic outlook we are finding between the *Silpa-Sastras* and the European perspectives in design.

Conclusions

The ancient Indians had a deep understanding of the human body dimensions with respect to *angula.* Among so many other dimensions of the body, selection of this body part as a basic unit must have been a result of thorough research by the *Silpins* and *Silpacharyas* through ages. Moreover, the relationship of dimensions stated in *Silpa-Sastras* is quite similar to the European interpretation. Thus, from the comparative analysis it can be inferred that the ancient Indian system of measurement was user specific and always derived dimensions from the human body. This system can still be understood and applied in relation to the modern system of dimensions to suit the modern needs through ancient understanding.

Another important point to note is the interconnectedness of Indian system which allowed flexibility along with scientific rationale. This is visible through variation of *hastas* and *angulas* allowing for flexibility and accommodating offsets to minimize human error at all scales of design simultaneously.

Acknowledgements

The authors want to express their gratitude to the Indian Knowledge Systems Division (IKS Division) of the Ministry of Education Government of India, for motivating them to research on *Silpa-Sastras.* The present article is the extension of the research investigation of the 5 months IKS-Internship on the topic: *'System of Measurement of Space in Ancient India & Europe - An Anthropometric Approach'* at IIT Roorkee's Centre of Indian Knowledge Systems by the author KJN under the supervision of author AA.

Declaration

KJN wants to extend his sincere thanks to the Ministry of Education Government of India, for the Prime Minister's Research Fellowship (PMRF ID: 2803611), which helped him to perform this study comprehensively.

Conflict of Interest

The authors certify that they do not have any conflict of interest to publish the manuscript in this journal.

Author Contributions

AA conceptualized and conducted the research. AA and RA formulated the conceptual framework of the manuscript. KJN collected the data and applied the conceptual framework under the supervision of AA & RA. KJN prepared the draft manuscript with S who helped in *Devanagari* script typing and checking of *Sanskrit* verses with the English explanation. AA && KJN analysed and interpreted the data along with critical revision of the article. AA & RA refined and finalized the research manuscript.

Data Availability

This article is an outcome of the extension of research investigation of the 5 months IKS-Internship on the topic: *'System of Measurement of Space in Ancient India & Europe - An Anthropometric Approach'* funded by the Indian Knowledge Systems Division of the Ministry of Education, Government of India. The data that support the findings of this study are available from the corresponding author AA & KJN upon reasonable request.

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