The rich, long history of scale as the imaginative inhabitation of a drawing provides a critique of the seductive but illusory exactness of 'full scale' representations in CAD.

Size matters: virtual scale and bodily imagination in architectural drawing

Paul Emmons

This small reflection on scale begins with remembering Jorge Luis Borges's tale of a certain seventeenth-century Spanish treatise describing a place where 'the Art of Cartography attained such Perfection' that a map of the Empire was made:

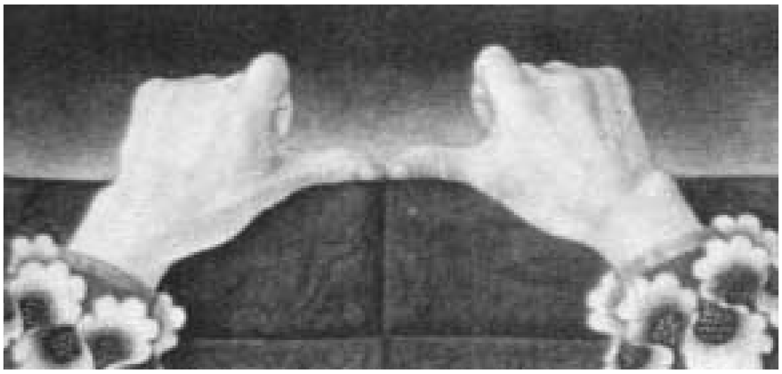
> *'whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that that vast Map was Useless, and not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars* [...]'.[1]

Borges's full-sized map enveloping its territory helps us to understand the delirious condition of scale drawing gone awry that occurs in CAD where buildings are represented at 'full scale'. After thousands of years of developing architectural drawing in scale, it behoves our thoughtful study, as scale is not merely a technical issue, but a question of the nature of architectural conception.

A scale drawing is more than a miniature; it has a consistent specific ratio to its object. The scale of an architectural drawing consists of equal parts measure and proportion where a unit of measurement is chosen and a ratio established between actual and apparent size.[2] Eighteenth-century surveyor Samuel Wyld defined scale as 'the true and exact Figure of the Plott, tho' of another Bigness'.[3] Scale is a stair providing means for ascending and descending between the great and the small or in music between the high and the low.[4] 'Scale' is simultaneously an instrument for the hand to make drawings and for the mind to imagine buildings.[5] Scale's presence in architecture is so enormous that it is almost invisible and has been used for at least several thousand years.[6] From the middle of the second millennium BCE, a statue of Gudea, leader of the City State of Lagash in present-day Iraq, is seated with a building floor plan resting on his lap. Also on the tablet are a stylus and a scale rule, showing fine divisions of the finger measure.[7]

Representing scale

Modern architectural scale drawing begins early in the Renaissance with the widespread use of paper and the separation of the architect from the construction site, so that early illustrated



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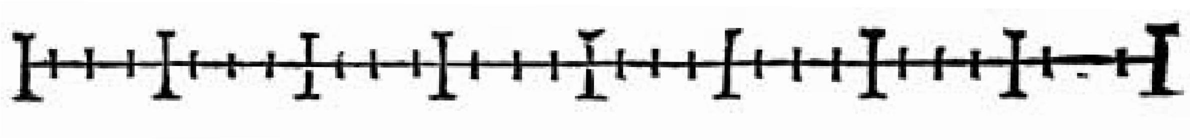
1 The use of hands for a foot measure. Filarete (Antonio Averlino), *Treatise on Architecture, Codex Magliabechianus* II, I, 140, Florence, Biblioteca Nazionale (c. 1400 – c.1465), Bk. I, Fol. 4r



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2 Half of the ancient Roman foot. Sebastiano Serlio, *The Five Books of Architecture*, Robert Peake, translator into English from Dutch (London, 1611), Bk. III, Ch. 4, Fol. 25

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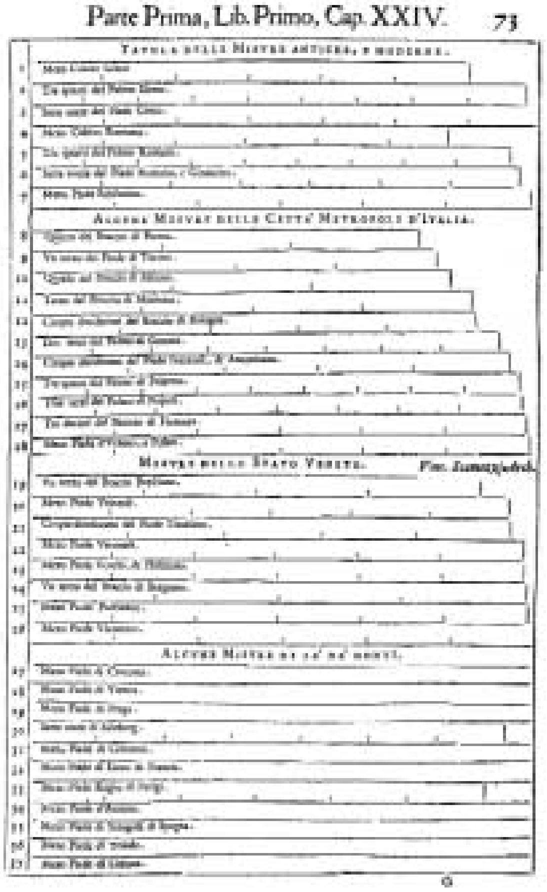

Parte Prima, Lib. Primo, Cap. XXIV. 73

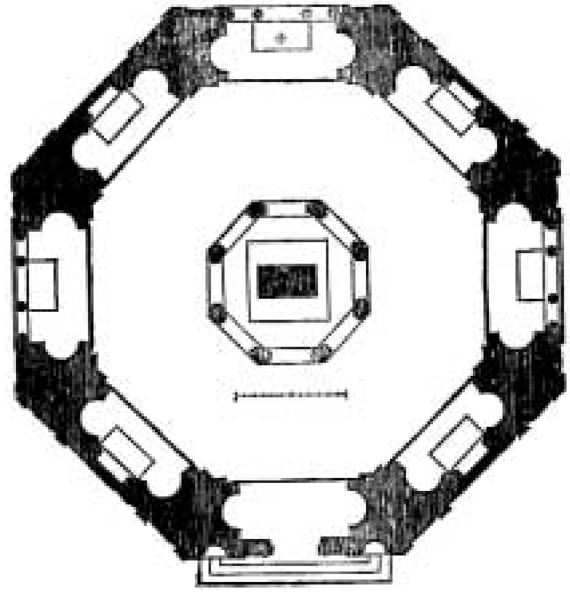
Tavola delle Misure antiche, e moderne.

Alcune Misure delle Città Metropoli d'Italia.

Misure dello Stato Veneto.

Alcune Misure di la da' monti.

3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3 Table of antique and modern measures. Vincenzo Scamozzi, *L'idea della architettura universale* (Venice, 1615), Parte Prima, p. 73

4 Plan of an octagonal temple with scale. Sebastiano Serlio, *Architettura*, translated by Jean Martin (Paris, 1547), Bk. V, p. 14r

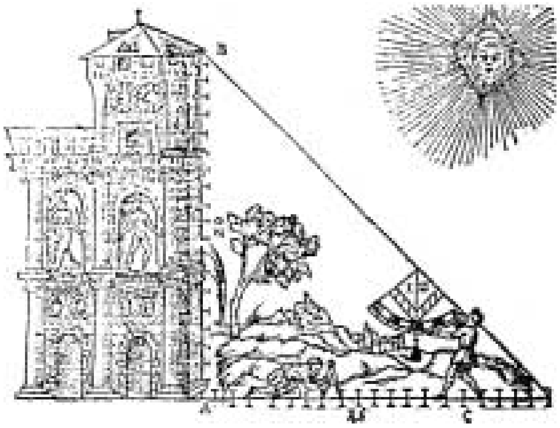
architectural treatises did not yet conventionalise representations of scale.[8] Measures were still directly related to the human body and exhibited similar variation *[1]*. Serlio and Palladio give the full-size dimension of the basic measures, because as Palladio explains, 'units of measurement differ just as cities and regions do [...]' *[2]*.[9] Scamozzi provides the comparative lengths of the same measure from various cities *[3]*. Even in the same place, the foot for velvet was shorter than the foot for cotton, reflecting valuations of different materials.[10] Furthermore, the treatises inconsistently provide drawing scales.[11] Palladio records primary dimensions directly on plans but their relationship to the drawings is unclear.[12] Serlio sometimes includes scales with plans and explains how to use them, suggesting it was not commonly understood:

> *'This plan was measured with the ancient palm.* [...] *I have scaled it down with the utmost care to this small, proportioned form so that the diligent architect can work out the measurements of the elements fairly accurately, using the small palms* [...] *on the line divided up into ten parts* [...] *Thus, taking a pair of compasses in hand some of the measurements of this building can be deduced.'*[13]

Occasionally, Serlio explains that he does not provide a scale because the plan is well-proportioned. 'I shall not put down all the measurements of the St. Peters because, being well proportioned, from one part of the measurements the whole can be derived.'[14] Serlio also interchanged the idea of measure with that of proportion when writing: 'Anyone who wanted this gateway to be larger or smaller should increase or diminish the feet'.[15]

Where Palladio and Serlio include graphic scales, they are almost always located on the primary vertical centreline of plan drawings and are shown as simple straight lines divided with short perpendicular marks *[4]*. Since early architectural drawings were made to represent procedures on the construction site, the scale lines derived from the knotted lines of ropes that were stretched on site to lay out the building. These measurements would stretch from the previously identified centreline of the building, just as they do in the drawings *[5]*. These early 'strings' of dimension lines, as we still call them today, have the arrows pointing in rather than out which probably derives from surveying techniques where, at the end of each length of chain, a pointed post was driven into the ground that had this shape and was called an 'arrow'.[16] An eighteenth-century treatise directs that the arrows are to be 'prick'd down' into the ground, using the same terminology for plan drawings.[17]

Scale drawing spread northwards from Italy during the sixteenth century. English maps first exhibited consistent scale about 1540.[18] The graphic scale on drawings became elaborated through representing the drawing tools used in scaling.[19] By the end of the sixteenth century, architectural scales were engraved on the sides of drawing tools, such as the proportional compass or the square.[20] Bar-shaped scales were developed with multiple scales on each side, including those from various locales *[6]*.[21] These tools provide the image of the graphic bars still in common use. The image consistently included a pair of dividers opened across the scale bar. Not merely



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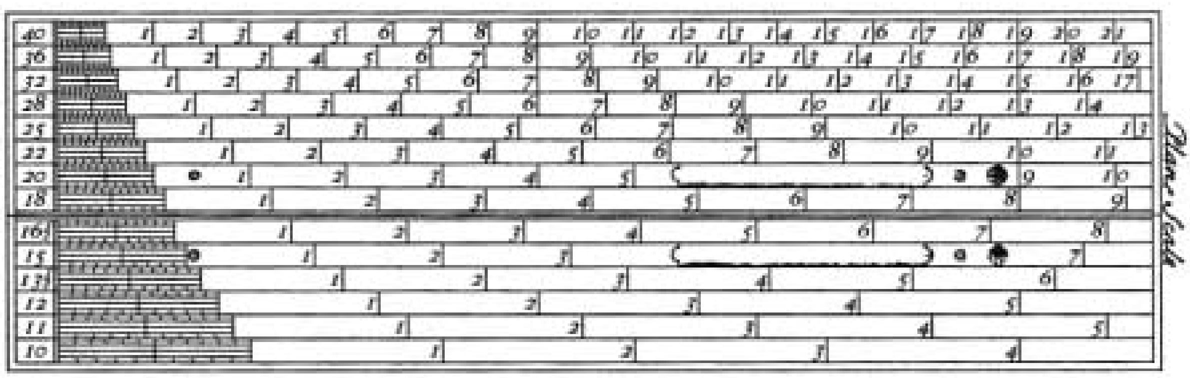

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5 Use of a quadrant to take heights. Leonard Digges, *A Geometrical Practical Treatize named Pantometria, divided into three books: Longimetra, Planimetra and Stereometria* (London: 1591), p. 13

6 Plain bar scale. John Robertson, *A Treatise of such Mathematical Instruments as are usually put into a portable case* (London, 1775), frontispiece

decorative, it explained visually how to use the scale because distances were taken off the scale with dividers and then applied to the drawing *[7]*. Edward Worsop explained in 1582:

> *'The knowledge, howe to apply the compasses to the scale, is commodious, for thereby ... the Lord sitting in his Chayre at home, may justly knowe, how many miles his Manor is in circuite.'* [22]

The representation of tools on drawings is most clearly seen in a sixteenth-century Italian map of England that has shadows cast by the legs of the divider across the scale bar *[8]*. Because units of measure were so variable, it was important to affix the scale to the drawing. The prominent size of the scale on plans drawn by sixteenth-century English surveyor and architect Robert Smythson (1536?–1614), well known for Wollaton Hall outside of Nottingham, is probably because the dividers are drawn in their full size on the paper.[23] Smythson was familiar with Italian and Dutch architectural treatises. The practice of using dividers to transfer scale onto a drawing continued through the nineteenth century.[24]

The sort of architectural scales in use through the twentieth century only recently became prevalent *[9]*.[25] In 1889, it was necessary to distinguish an ordinary scale from a 'plotting scale, with the divisions on a fiducial edge, by which any length may be marked off on the paper without using dividers'.[26] The technique of using the scale directly on the paper replaced dividers around the end of the nineteenth century.[27] An 1898 draughting manual cautioned: 'A distance should rarely be transferred from the scale to the drawing by the dividers, as such procedure damages the scale if not the paper'. Even in 1918 Thomas French had to declare: '*Never* take dimensions by setting the dividers on the scale'.[28]

Scaled literature

During the seventeenth and eighteenth centuries, questions of scale grew to prominence with the development and use of the telescope and microscope. These devices, in extending the ability of the senses, made new worlds visible. This scalar fascination was explored in *Gulliver's Travels* by Jonathan Swift (1726) and *Micromégas* by Voltaire (1738–1752), both of which refer to telescopes and microscopes.[29] When Voltaire was exiled to England for three years, he developed a friendship with Jonathan Swift. Like an architect making a drawing, these stories describe a person venturing into an imaginary world of another size.

Both stories begin with bodily scale relationships. In Lilliput, Gulliver encounters 'a human Creature not six Inches high' giving him the scale of one inch to Gulliver's foot.[30] In his next voyage, Gulliver's scale proportionally becomes that of the Lilliputians as he meets a 72 foot tall farmer, making both lands the same ratio of 1:12, translating neatly between imperial feet and inches.[31] Swift's original illustrations are limited to maps of the territories Gulliver accidentally discovered that show no scale and allows them to alternate between gargantuan and tiny.[32]

Voltaire gives Micromégas, a traveller from a Sirian planet, the Vitruvian Doric proportions of a well-

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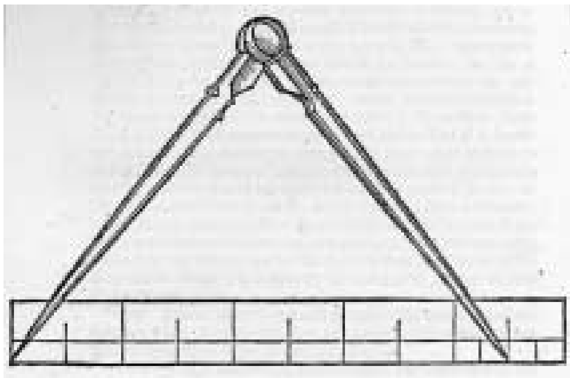

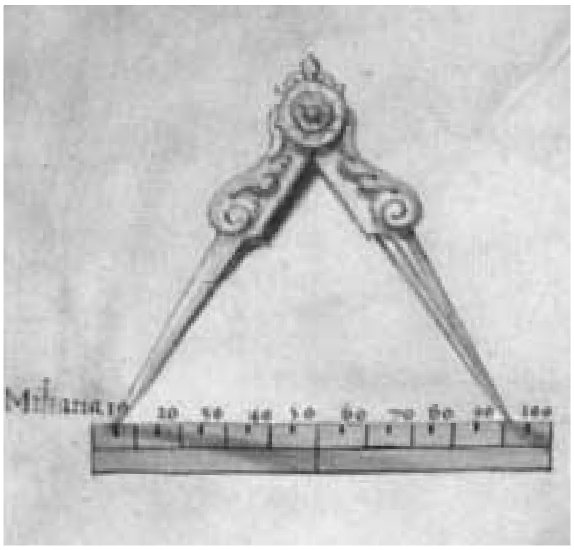

7 Use of a scale illustrated. Edward Worsop, *A Discoverie of Sundrie errours and faults daily committed by Landemeaters, ignorant of Arithmetike and Geometrie written Dialoguewise* (London: Henrie Middleton, 1582), np

8 Drawn dividers casting a shadow on a scale. Map of the British Isles, c. 1534–46. Anonymous, British Library, Cotton MS. Augustus I.i.9

9 Plotting scale. W. E. Worthen, Editor, *Appletons' Cyclopaedia of Technical Drawing Embracing the Principles of Construction as applied to Practical Design* (New York: Appleton, 1889), p. 49

10 Micromégas picks up the ship of humans. Charles Monnet (1732 – after 1808)

formed man, but at enormous size, standing 120,000 Parisian feet tall, which is 24,000 times the size of a human.[33] This proportion probably derives from Voltaire's *The Elements of Sir Isaac Newton's Philosophy* (1737), wherein he calculated the height of each planet's possible inhabitants in proportion to the planet's circumference due to gravity.[34] Micromégas, seeing proportion everywhere, finds small residents on their small world. During Voltaire's lifetime, there was a spirited debate between Newtonians and Cartesians about the shape of the earth. A French survey team travelled to the Arctic Circle to measure the length of a meridian to resolve the conflict. Voltaire was well aware of this actual voyage and used it to populate his story when Micromégas discovers a ship returning from measuring the meridian of the Arctic Circle *[10]*.[35] It seems that Voltaire was treating the proportional relationship between Micromégas and the tiny humans as the relation between planet and person because the earth's circumference is about 24,000 miles, Micromégas's given proportion. Furthermore, Voltaire gives Micromégas's circumference like he did for planets, an otherwise unusual measurement for a creature, and in his scientific writings refers to the planets with the male pronoun 'he', also the gender of Micromégas. In the story, the humans surveyed the reclining Micromégas to determine his height exactly as they did in reality with the earth at the North Pole. Voltaire's seven chapters of Micromégas match his proportional height as well as the number of known planets.

Hooke's *Micrographia* and Malebranche's Cartesian dream

A key source for both Swift and Voltaire was *Micrographia* (1665), prepared by Robert Hooke for the Royal Society to carefully record microscopic and telescopic observations, 'producing new Worlds and *Terra-Incognita's* to our view'.[36] Hooke was also Surveyor for the City of London and designed numerous buildings, including the Royal College of Physicians, Bedlam Hospital, and many city churches with his friend Sir Christopher Wren after the Great

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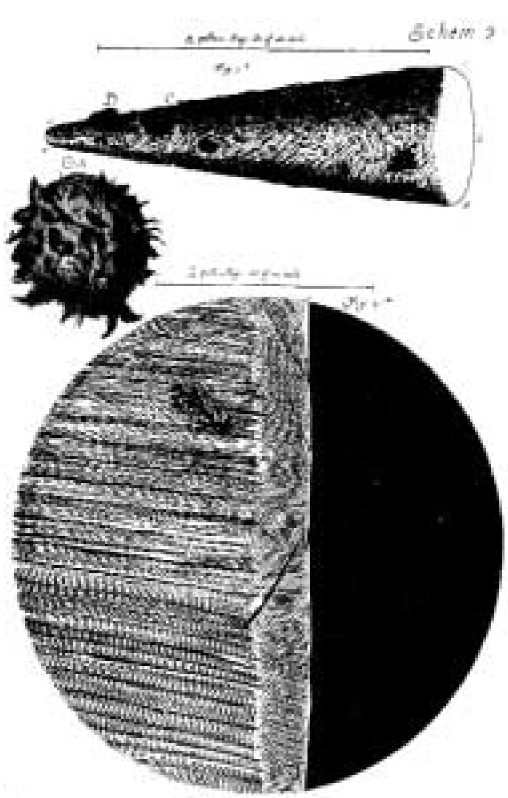

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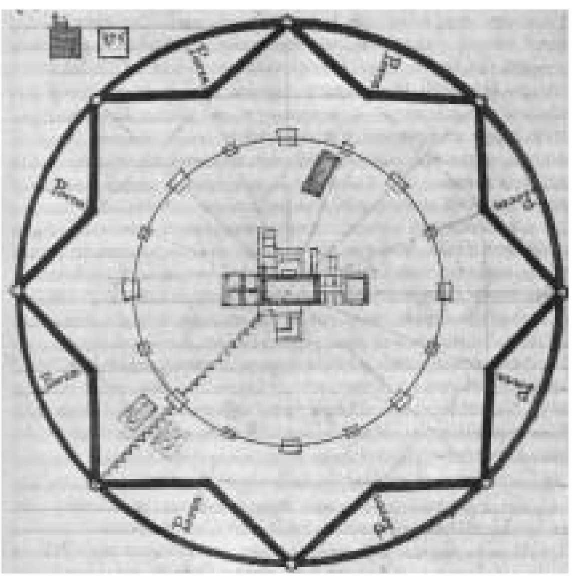

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Fire.[37] He transferred his familiarity with scale from architectural drawing to the microscope.

Hooke organised his microscopic observations in *Micrographia* progressively from simple to complex, like a geometer ascending from point, line, plane to volume and the chain of being from mineral to vegetable and animal. He began with observing the point of a pin under the microscope, which, as Voltaire wrote, 'abounds with Eminences and rugged parts'.[38] He next analysed a dot made by a pen, and in a scalar reverie imagined this dot as the earth in space [11]. Emphasising the importance of total engagement for observations through the microscope with 'Sincere Hand and Faithful Eye', Hooke advises: 'begin with the *Hands and Eyes*, and proceed on through the *Memory*, to be continued by the *Reason*; nor is it to stop there, but to come about to the *Hands and Eyes* again'.[39]

Hooke explained his method of determining the microscope's scale of magnification by looking with one eye through the microscope as the other naked eye examines a ruler, simultaneously engaging both scales:

> *'At the same time that I look upon the Object through the Glass with one eye, I look upon other Objects at the same distance with my other bare eye; by which means I am able, by the help of a ruler divided into inches and small parts, and laid on the pedestal of the microscope, to cast, as it were, the magnified appearance of the Object upon the Ruler, and thereby exactly to measure the Diameter it appears of through the Glass, which being compared with the Diameter it appears of to the naked eye, will easily afford the quantity of its magnifying.'*

11 Magnified pin, ink spot and razor edge. Robert Hooke, *Micrographia, or Some Physiological Descriptions of Minute Bodies made by Magnifying Glasses with Observations and Inquiries thereupon* (London: Joseph Martyn and James Allestry, 1655), plate II

12 Scale and plan of the city of Sforzinda, Filarete (Antonio Averlino), *Treatise on Architecture, Codex Magliabechianus* II, I, 140, Florence, Biblioteca Nazionale (c. 1400 – c. 1465), Bk. VI, Fol. 43r

13 The prudent architect walking with a compass. Philibert de l'Orme, *Le premier tome de l'architecture* (Paris, 1567), Fol. 51

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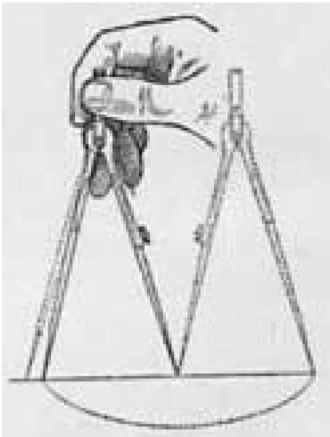

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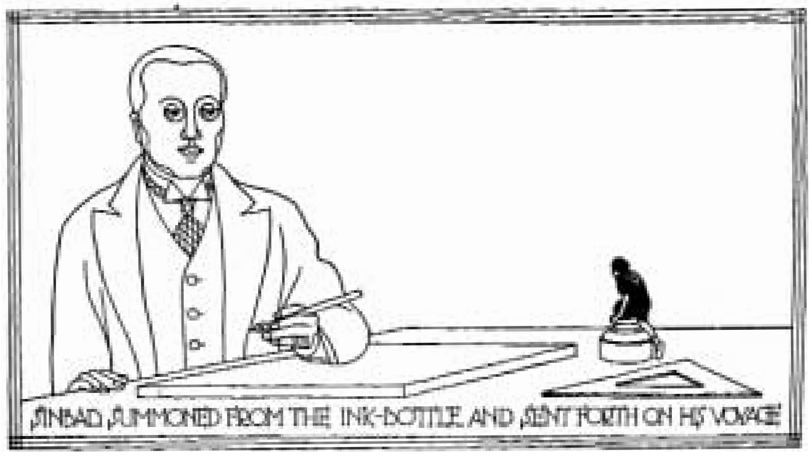

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14 The 'walking' of dividers for measuring. Frederick Willson, *Theoretical and Practical Graphics* (New York: Macmillan, 1898), fig. 10, p. 12.

15 'Sinbad summoned from the ink bottle and set forth on his voyage', Claude Bragdon, *The Frozen Fountain, being essays on architecture and the art of design in space* (New York: Knopf, 1924), p. 1

Since nature only exists in full scale, imagination is required to project a change of scale and it occurs through relation to a stable entity, our own body. Lilliput seems ordinary without Gulliver's looming presence.[40]

Nicolas Malebranche (1638–1715), a devout Cartesian, was also stimulated by these new discoveries but in a different direction. His first enthusiastic reading of Descartes 'caused him such violent palpitations of the heart that he was forced to interrupt his reading in order to breath', although he did not realise that this interconnection between mind and body already denied his new found Cartesianism.[41] Malebranche identified the relativity of perception by performing a thought experiment of an infinitely small creature on an infinitely small ball compared with an infinitely large creature on an infinitely large ball, which appeared identical:

> *'Since it is not certain that there are two men who view the same object as having the same size, and since sometimes even the same man sees things larger with his left eye than with the right* [...], *it is clear that we must not rely on the testimony of our eyes to make judgments about size. It would be better to listen to reason* [...]'[42]

Like Voltaire and Swift, Malebranche concludes there is no such thing as true extent, only relative size proportional to ourselves. However, Malebranche's solution is to distrust the senses and rely on the mind's presumed direct access to ideas. The material world, 'the main cause of all our errors and miseries', he contrasts with the mind, which 'through God receives its life, its light, and its entire felicity'.

Cartesian computing and the scalar imagination

CAD applies this Cartesian approach to scale in architectural drawings by forgoing the senses to assume scale is solely in the mind. Data is recorded at 1:1 or full scale, but the size of the screen image indefinitely varies as the operator zooms in or out to consider various aspects, creating the inability to put them into a perceivable relation to the operator's body. CAD only requires scale when printing in paper space. As Descartes transformed geometrical constructions into mathematical formulas, the CAD scale factor is a multiplier that converts the full-size measurement into a scale for the plot. This relationship is merely numerical and must be known to the mind since it is not intuitive. This odd relation to scale is revealed by the necessity to put text into scale rather than the drawing so that the lettering is printed in an appropriate size. Only in paper space does the CAD representation take on a synoptic scale in relation to the observer. It is at this moment that many computer-generated drawings reveal their scalar limitations and fail to allow the imagination to focus on particular sets of issues.

CAD 's myth of full-scale drawing is in fact the absence of scale. This absence makes it more likely that the designer looks at the image as an object rather than projecting oneself into the image through an imaginative inhabitation. Scaled sight is not an abstraction; it is achieved through judging the size of things in relation to ourselves. With CAD, we do not operate at any particular scale because the image is severed from our frame of reference. In moving from hand drawings to CAD, 'man the measure' is replaced with 'man the measurer'.

Since architectural drawing is a source of the imagination rather than a recording of prior ideas, scale assists in this effort. As handbooks advise, you must learn to think within a scale rather than translate from actual measure.[43] This valuable approach misleads some to believe that full scale is most desirable. Yet, the fiction of scale aids the architect in composing a story by providing a synoptic view that consistently asks for particular sorts of information. While Cartesian approaches assume that scale is merely numerical dimensions known to the mind, early explanations of scale show that empathetic bodily projection is critical to imagining a future edifice.

Filarete explains how the architect imaginatively inhabits a scale drawing by drawing a square 150 braccia on a side and divided each into 15, 10 braccia parts.[44] Filarete's early graphic scale was a

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proportional field rather than a line that related to the surveying of the site *[12]*:

> *'If you want to understand this diminution clearly, take these compasses and divide one of these parts into ten. Then with the compasses, erect a perpendicular line that is three times as long as one of these parts* [... *Make*] *a human figure of the same size. Then consider it to be as large as this. Then you would understand the diminution of the braccia and of every other measure.'*[45]

Filarete's scale figure is not a human measuring stick, but a way to imagine measure through the human body like miniature humans as traditional representations of the soul.[46] With measures deriving from the human body, the tiny body of the architect *is* the measure. Filarete continues:

> *'by pretending that man is small, all the measures drawn from him are small* [...] *Even though this drawing seems small in appearance to us who are large, if men were as small as it is, it would seem as large to them as it will to us when it is all walled up and completed.'*

Filarete drew his explanation from Alberti's more philosophical discussion in *On Painting*:

> *'*[*If*] *the sky, the stars, the seas, the mountains and all living creatures, together with all other objects, were, the gods willing, reduced to half their size, everything that we see would in no respect appear to be diminished from what it is now* [...] *all these are such as to be known only by comparison. Comparison is made with things most immediately known. As man is best known of all things to man, perhaps Protagoras, in saying that man is the scale and the measure of all things, meant that accidents in all things are duly compared to and known by the accidents in man.'*[47]

Voltaire chides Malebranche in *Micromégas* and writes in his book on *Newton's Philosophy*: 'Father Mallebranche, whose Genius was more subtle than true, and who always consulted his Meditations, but not always Nature, adopted the Elements of Descarts without Proof'. Voltaire argues that our senses do not deceive us, but they must assist each other mutually, as Hooke's methodology showed. For example, the idea of distance is known only through combining touch with vision.[48] The making of architectural drawings must engage the entire body into the physical act of imagination.

Imaginative inhabitation of drawing

The synoptic scalar view invites imaginative inhabitation of the drawing. When no clear relation exists between body and drawing, this inhabitation is at best partial and shifting. Perhaps this relation of the designer in the drawing, like Hooke's two eyes focusing simultaneously at full and scaled relations, explains why dividers were used for centuries to scale plans. The compass *becomes* the architect walking across the drawing *[13]*.[49] As the draughtsman's language shows: the 'foot' of the compass grips the paper and the two 'legs step off paces' to measure a distance *[14]*.[50] John Soane, who kept a tiny set of drawing instruments including an ivory scale in a walking stick, made a direct connection between the architect's bodily measures and drawing measures.[51] The shaft of the cane holds two rules that can be joined to measure 60 inches which is a fathom or two paces. Gulliver, like the architect's scalar imagination, walked across a gigantic map, explaining that: 'I [measured the city] myself on the Royal Map, which was laid on the Ground for me, and extended an hundred Feet; I paced the circumference Bare-foot, and computing by the Scale, measured it pretty exactly'.[52] American architect Claude Bragdon invented the tiny character of Sinbad, whom he described as an everyman, for his 1924 treatise. The book begins with Sinbad climbing out of Bragdon's ink bottle to represent his imagination perambulating through architectural drawings *[15]*.[53] Borges's story evaluates the chimeric notion of full scale as exactness. As in CAD, full scale renders the entire notion of scale useless and fails to achieve precision which is necessarily defined by a point of view.[54] Instead, a drawing is scaled for its destination toward a *fitting* understanding.[55] Architectural drawing assumes a plurality of worlds to imagine an environment inferior to our size so that we may comprehend a possible place superior to us.[56]

Notes

1. Jorge Luis Borges, 'On Exactitude in Science' ('*Del rigor en la ciencia*'), in *Collected Fictions*, trans. by Andrew Hurley (New York: Penguin, 1998), p. 325.
2. Cecil D. Elliott, 'The Variety of Scale', *Journal of Architectural Education* (1963), 35-37.
3. Samuel Wyld, *The Practical Surveyor, or Land-Measuring made easy* (London, 1725), p. 111.
4. Dorit Tanay, *Noting Music, Marking Culture: The Intellectual Context of Rhythmic Notation, 1250–1400* (Holzgerlingen: American Institute of Musicology, 1999).
5. Raymond Nicyper, *Scale Drawing: Graphics Underlay Guides* (Westport: Graphicraft, 1973).
6. Maya Hambly, *Drawing Instruments 1580–1980* (London: Sotheby's Publications, 1988). Both the Ancient Egyptians and the Greeks used scale. The drawings inscribed in the wall of the Temple of Apollo at Didyma identified by Lothar Haselberger show a column drawing with the width at full scale while the height is at one-sixteenth scale (the number of fingers in a foot). Roman bronze fixed proportional compasses have been uncovered from the beginning of the Christian era. H. W. Dickinson, 'A Brief History of Draughtsmen's Instruments', *Transactions of the Newcomen Society,* 27 (1949-51), pp. 73-83, 73. A fixed proportion bronze Roman compass at the British Museum is pictured in: O. A. W. Dilke, *Mathematics and Measurement* (London: University of California Press, British Museum, 1987), frontispiece. Gordon Higgott, 'Book Review, Maya Hambly, *Drawing Instruments 1580-1980*', *Journal of the Society of Architectural Historians,* 49. 1 (March, 1990), 111–112.
7. Flemming Johansen, *Statues of Gudea Ancient and Modern, Mesopotamia Volume 6* (Copenhagen: Akademisk Forlag, 1978), p. 10.
8. Hambly, *Drawing Instruments*, p. 115.
9. Andrea Palladio, *Four Books on Architecture*, trans. by Robert

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Tavernor and Richard Schofield (Cambridge, MA: MIT Press, 1997), I.13, p. 19.

10. 'In every country there are different measures according to the place and things measured. As the thing is more precious, so the measure is larger or smaller even with a measure of the same name and properties, as, for instance, the braccio. The braccio for measuring wood is longer than that for wool. The braccio for wool is longer than that for velvet [...] The braccio is longer in Rome than in any other place [...] Perhaps this is because the braccio took its origins from large men. Since Rome was still the largest city, perhaps they wished to accord [with this greatness].' Filarete, *Treatise on Architecture*, trans. by John Spencer (New Haven: Yale University Press, 1965), I. 4r, p. 9. A braccio was a common measure taken from the length of the arm. For a record of different Renaissance measures see: William Parsons, *Engineers and Engineering in the Renaissance* (Cambridge MA: MIT Press, 1967), Appendix B 'Measures of Length', pp. 625-35.
11. Palladio shows scales in 22 drawings.
12. 'For ease of comprehension and to avoid the time and tedium which would be inflicted on the reader were I to describe the dimensions of every part in minute detail, I have indicated all the dimensions in the designs with numbers.' Palladio, *Four Books on Architecture*, IV. 6, p. 221.
13. Sebastiano Serlio, *Sebastiano Serlio on Architecture, Volume One, Books I–V of 'Tutte L'Opere D'Architettura et Prospetiva'*, trans. by Vaughan Hart and Peter Hicks (New Haven: Yale University Press, 1996), III., p. 187.
14. Serlio, op. cit., III, p. 127.
15. Sebastiano Serlio, *Sebastiano Serlio on Architecture, Volume Two, Books VI and VII of 'Tutte L'Opere D'Architettura et Prospetiva'*, trans. by Vaughan Hart and Peter Hicks (New Haven: Yale University Press, 2001), *Extraordinary Book*, p. 462.
16. Leonard Digges, *A Geometrical Treatize named Pantometria, divided into Three Bookes, Longimetra, Planimetra, and Stereometria* (London: Adell Jeffes, 1591).
17. Samuel Wyld, *The Practical Surveyor or, the Art of Land-Measuring Made Easy* (London: 1725), with notes by David Manthey (Arlington, VA: Invisible College Press, 2001), pp. 6, 199.
18. P. D. A. Harvey, *Maps in Tudor England* (London: British Library, 1993), p. 8.
19. 'In one of the corners at the bottom, make a Scale equal to that by which the Plott was laid down, adorning it with Compasses, Squares, Ovals &c.', Wyld, *The Practical Surveyor*, p. 113.
20. Dickinson, 'A Brief History of Draughtsmen's Instruments'; Hambly, *Drawing Instruments*, p. 115.
21. John Robertson, *A Treatise of such Mathematical Instruments as are usually put into a portable case*, facsimile of the third edition (Arlington, VA: Invisible College, 2002 [1775]).
22. Edward Worsop, *A Discoverie of Sundrie errours and faults daily committed by Landemeaters, ignorant of Arithmetike and Geometrie written Dialoguewise* (London: Henrie Middleton, 1582) np. Worsop's student in this dialogue proclaims that: 'I have seene the like lines, and compasses set in mappes, but I never understood what they meant till nowe [...] The opening and extending of the compasses upon the scale [is] the application of the compasses to the scale'.
23. Mark Girouard, *Robert Smythson and the Elizabethan Country House* (New Haven: Yale University Press, 1983).
24. W. M. Minifie, *A Text Book of Geometrical Drawing for the use of Mechanics and Schools* (Baltimore: Minifie & Co., 1849), p. 28.
25. Dickinson, 'A Brief History of Draughtsmen's Instruments', pp. 73–83, 81.
26. W. E. Worthen (ed.), *Appleton's Cyclopedia of Technical Drawing, embracing the Principles of Construction as applied to Practical Design* (New York: D. Appleton, 1889), p. 49.
27. Worthen, *Appleton's Cyclopedia of Technical Drawing*, p. 49. 'The scale should be written on every drawing, or the scale itself should be drawn on the margin [...] the paper itself contracts or expands with every atmospheric change, and the measurements will therefore not agree at all times with a detached scale; and, moreover, a drawing laid down from such a detached scale, of wood or ivory, will not be uniform throughout, for on a damp day the measurements will be too short, and on a dry day too long. Mr. Holtzapffel has sought to remedy this inconvenience by the introduction of paper scales; but all kinds of paper do not contract and expand equally, and the error is therefore only partially corrected by his ingenious substitution of one material for another.'
28. Frederick Newton Willson, *Theoretical and Practical Graphics, an Educational Course on the Theory and Practical Applications of Descriptive Geometry and Mechanical Drawing* (New York: Macmillan, 1898), pp. 16–17. 'Plotting scales are scales with the divisions on a fiducial edge, by which any length may be marked off on the paper without using dividers.' Worthen, *Appleton's Cyclopedia of Technical Drawing*, p. 49; Thomas E. French, *A Manual of Engineering Drawing* (New York: McGraw-Hill, 1918), p. 37 and see pp. 21-22 (emphasis in original).
29. Micromégas uses a diamond microscope to see the diminutive humans that he calls, like bacteria: 'a little animalcule in academic dress'. Gulliver was studied by the giants with a 'Magnifying-Glass'. Jonathan Swift, *Gulliver's Travels, Complete, Authoritative Text with Biographical and Historical Contexts, Critical History and Essays from Five Contemporary Critical Perspectives*, ed. by Christopher Fox (New York: Bedford, 1995), pp. 108, 111. Gulliver mentions Gresham College, meeting place of the Royal Society, p.113.
30. Swift, *Gulliver's Travels*, p. 42; Vaughan Hart, 'Review, *Gulliver's Travels*, Jonathan Swift: Case Studies in Contemporary Criticism', *Utopian Studies*, 22 March 1998.
31. Swift uses architectural elements to provide an understanding of human scale in describing Gulliver as unable to ascend a stair with risers that are six feet tall, Swift, *Gulliver's Travels*, p. 93.
32. Lewis Carroll, on the other hand, did provide a map which showed only ocean (i.e. was blank) and included a scale, but one that was without any numerals. Lewis Carroll (C. L. Dodgson), *The Hunting of the Snark* (London: Catalpa Press, 1974).
33. Micromégas was also used by Daniel Libeskind to title a series of architectural drawings. Daniel Libeskind, *Micromégas, Symbol and Interpretation. Cranbrook Academy of Art* (Zurich: ETH, 1981).
34. Voltaire gives the earth's circumference as 126,249,600 Paris feet which are 0.78" longer than English and explains that 'from that alone may be derived the whole system of attraction'. Voltaire, *Letters Concerning the English Nation* (1733), (Oxford: Oxford University Press, 1999), p. 69.
35. Voltaire wrote in 1733: 'M. Picart's clarification of the meridian corrected earlier efforts by showing there are 70 English miles to one degree of latitude',

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which was described by Voltaire as 'sublime verity with the aid of a quadrant and a little arithmetic'. Voltaire, *Letters Concerning the English Nation*, p. 69.

36. Robert Hooke, *Micrographia, or Some Physiological Descriptions of Minute Bodies made by Magnifying Glasses with Observations and Inquiries thereupon* (London: Joseph Martyn and James Allestry, 1655).
37. Lisa Jardine, *The Curious Life of Robert Hooke, The Man Who Measured London* (New York: Perennial, 2003). One of Hooke's innovations was the development of the double-hung window. Stephen Inwood, *The Forgotten Genius: The Biography of Robert Hooke 1635–1703* (New York: MacAdam, 2003).
38. Voltaire, *The Elements of Sir Isaac Newton's Philosophy*, translated by John Hanna (London: 1738), 23.
39. Hooke believed a researcher needed constant and fruitful interaction between Baconian fact and Cartesian theory. Stephen Inwood, *Forgotten Genius*, p. 60.
40. After returning to his own kind from the land of the giants, Gulliver found that ordinary sized men appeared to him as Pygmies. Swift, *Gulliver's Travels*, p. 142.
41. André Robinet, *Système et existence dans l'oeuvre de Malebranche* (Paris: J. Vrin, 1965), p. 12. Cited in: Nicolas Malebranche, *The Search after Truth, Wherein are treated the Nature of Man's Mind and the Use He Must Make of It to Avoid Error in the Sciences*, trans. by Thomas Lennon and Paul Olscamp, (Cambridge: Cambridge University Press, 1997), p. viii.
42. Malebranche, *The Search after Truth*.
43. 'For example, if you use a scale of 1"=10' and the actual measurement on the drawing happens to be 3-1/2", you do not say that the particular line is three and one-half inches; rather, read the measurement as 35 feet.' John Traister, *BluePrint Reading for the Building Trades* (Carlsbad, CA: Craftsman, 1985), p. 119.
44. A *braccia* is a traditional Italian measure from the elbow to the fingertip that is close to two feet in length.
45. Filarete, VII (47r), p.81.
46. Rosalie Osmond, *Imagining the Soul: A History* (Stroud: Sutton, 2003).
47. Alberti, *On Painting*, p.53 (Bk 1, 18). According to Rykwert et. al., Alberti probably knew Protagoras from Diogenes Laertius, *De vitis philosophorum*, IX, 51. Of Protagoras's surviving fragments, the most famous is the *homo-mensura* (man-measure) statement (DK80b1): 'Of all things the measure is man, of the things that are, that [or 'how'] they are, and of things that are not, that [or 'how'] they are not.'
48. Similarly, Swift, a friend of Bishop Berkeley, emphasises that 'nothing is great or little otherwise than by Comparison'.
49. Marco Frascari, 'The Compass and the Crafty Art of Architecture', *Modulus* (1993) 1–14; L. R. Shelby, 'Medieval Masons' Tools II. Compass and Square', *Technology and Culture*, 6:2 (Spring, 1965), 236–248. The Greek mythical inventor of the compass is Perdix, nephew of Daedalus (Diodorus Siculus, IV.76; III. 58).
50. Minifie, *A Text Book of Geometrical Drawing for the use of Mechanics and Schools*, p. 28; Willson, *Theoretical and Practical Graphics*, p.12; French, *A Manual of Engineering Drawing*, pp. 22–23. Greek words for compass include *Diabetes* meaning walking or stepping across.
51. I wish to express my thanks to the Soane Museum for allowing me to examine the walking stick. Soane purchased it believing it belonged to Sir Christopher Wren but it was actually made much later. Higgott, 'Review: Maya Hambly, *Drawing Instruments*', pp. 111–112.
52. Swift, *Gulliver's Travels*, p. 115.
53. Claude Bragdon, *The Frozen Fountain, being essays on architecture and the art of design in space* (New York: Knopf, 1924).
54. '[...] And then comes the grandest idea of all! We made a map of the country, on the scale of a mile to the mile! "Have you used it much?" I enquired. "It has never been spread out yet" said Mein Heer, "The farmers objected: they said it would cover the whole country and shut out the sunlight! So we now use the country itself, as its own map, and I assure you it does nearly as well."' Lewis Carroll, *Sylvie and Bruno Concluded* (New York: Macmillan, 1893).
55. Richard Neutra remembered: 'In the year 1900, Adolf Loos started a revolt against the practice of indicating dimensions in figures or measured drawings. He felt, as he often told me, that such a procedure dehumanizes design. "If I want a wood paneling or wainscot to be of a certain height, I stand there, hold my hand at that certain height, and the carpenter makes his pencil mark. Then I step back and look at it from one point and from another, visualizing the finished result with all my powers. This is the only human way to decide on the height of a wainscot, or the width of a window."' Richard Neutra, *Survival Through Design* (New York: Oxford University Press, 1954), p. 300.
56. Marco Frascari, 'The Body and Architecture in the Drawings of Carlo Scarpa', *RES* 14 (Autumn 1987), pp. 123–142.

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