VITRUVIUS AND THE LIMITS OF PROPORTION[1]

I come to the present topic with some trepidation. Unlike many of the contributors to the present volume, I am not a Vitruvian scholar, nor does my main interest even in this paper lie with Vitruvius himself as such. Rather, I wish to consider the (exceptionally rich) evidence he provides us for some more general questions of Roman metrology. This inquiry does not have to do with antiquarian questions of the "correct" modern equivalents for various Roman measurements; I suspect those questions are ultimately unanswerable and even incoherent for reasons beyond the scope of this paper. I ask instead what styles or modes of measurement were available to the Romans and what considerations dictated their used in particular contexts. This is a question I address as a broad historical matter elsewhere, but Vitruvius' text proves so metrologically rich that it deserves to be treated on its own here.

De Architectura is, of course, one of the Roman texts densest in measurements, along with a number of medical and agricultural works and the writings of Frontinus and the Elder Pliny. Even among the works just mentioned, it stands out both for the way measurement is crucial to the tasks at hand (a *Natural History* could be written without measurements) and for how measurement is explicitly thematized (Scribonius Largus has only two sentences to say on the measures he uses in his drug recipes). Vitruvius is presumably a product of the metrological culture he is embedded in, just as any author is a product of his or her culture more broadly. At the same time, he presumably occupies a unique position and trajectory within that culture, again just like any other author. So what I want to consider here is precisely how he reflects and inflects the metrology of his day.

The most obvious starting point for such an investigation is probably the Vitruvian feature best known outside professional Classics—the role of proportion in *de Architectura*. Some of this contemporary reputation presumably derives from the even greater fame of Leonardo's later illustration of so-called Vitruvian Man, based on 3.1.2:

For the human body is so designed by nature that the face, from the chin to the top of the forehead and the lowest roots of the hair, is a tenth part of the whole height; the open hand from the wrist to the tip of the middle finger is just the same; the head from the chin to the crown is an eighth, and with the neck and shoulder from the top of the breast to the lowest roots of the hair is a sixth; from the middle of the breast to the summit of the crown is a fourth….[2]

But, of course, proportion is much more important to Vitruvius than just this passage (though I will return to it a couple of times for further comment). He uses proportions for measurement in numerous passages, many involving multiple instances each.[3] Moreover, those proportions are used in a variety of contexts. Beyond the most famous cases of the human body and of the various architectural orders, for instance, there are features of theaters, baths, and harbors; design of foundations and staircases, and the sundial. Perhaps most significant, however, is the thematization of proportion. *Symmetria*, the formal, mathematical correspondence of the various elements of the whole (1.2.4), is one of Vitruvius' six basic design principles (1.2.1), and in fact far the most commonly mentioned of the set (84 times; Wilson Jones 2000.40]. Mentions of *proportio* come to almost half again as many mentions. And, of course, the proportional account of the human body itself is not a random piece of observational physical anthropology. It is an argument for the naturalness of various measures and building styles which are made analogous by appeal to proportionality.

This much will likely be familiar to many readers. I would like now to complicate the picture in a couple of related ways. First, I would suggest that we should not declare simply that this or that measurement is by proportion or not. In principle, there is a range of measurement styles. Different ones are more (or less) "anchored" in various intersubjectively available standards—engraved marble stelai or platinum bars, the movements of celestial bodies, vibrating cesium atoms, and so on. Second, even aside from the existence of the range, I want to suggest that Vitruvius' commitment to measurement-by-proportion (of any sort) actually involves at least two different phenomena. One is formal and presumably deliberate. It is a part of a self-fashioning strategy. Offering a "science" of proportions systematizes architecture into an *ars* and elevates it by tying it to even higher status discourses. The other phenomenon is more pragmatic and perhaps unconsciously absorbed from the broader culture. Roman measurement in general relies heavily on proportions. That reliance is caused to a lack of technologies, both mechanical and administrative, for standardization of units (or is caused by it or likely both). In the first main part of my paper, then, I want to examine which of these motivations seems to apply in cases where Vitruvius does appeal to proportionality. In the second part of the paper, I turn instead to instances where Vitruvius goes against the tendency, both his own and the culture's, towards proportionality. I will note a number of other metrological strategies in *de Architectura*, and try to show that they contain evidence for a more anchored style of measurement. This too will be explained as a response to real-world constraints.

My theoretical point about the range from proportional to anchored measurement will largely be worked out in the course of the more empirical analyses. I will start by assessing some of Vitruvius' more minor strategies along these lines, then work towards the more important ones.

A number of Vitruvius' designs, most notably but not solely those for theaters (5.6) and sundials (9.7), depend on geometric construction by compass and straight-edge.[4] Though these are not described in terms of proportions, that is of course what they generate. The straightedge, after all, is an unmarked ruler, and the compass is (among other things) a device for reproducing arbitrary quantities. When the instructions tell the reader to divide a line segment into three parts, they will be in equal proportion to each other, but not in any particular relationship to the parts of a line another person draws. These constructions even have the advantage over simple ratios of allowing proportions involving irrational numbers (as in the doubling of the square; 9.pr.4-5), and of being able to incorporate curves of various sorts. However, it is worth noting two special features of geometric construction in Vitruvius. One is its relatively limited distribution. Generally it is only used when one of those special properties (use of curves or irrational numbers) are salient. But note, on the other hand, that the purity of geometrical proportionality is limited to design; it can't be reproduced directly at construction scale like direct measurement without the introduction of further methods.

A more intriguing case is that of quantities measured in ostensibly fixed units. Metrological treatises show that Romans had available a number of named units, of various sizes, to measure, for instance, length, volume, or time. In principle these could have been combined as a way of producing more precise measurements. Instead of saying "about two feet" or even just "two feet" one could have specified "1 foot, 3 palms, and two digits." In fact, however, that is quite rare. Romans far more commonly used multiples and fractions of a single unit to render any individual measurement or indeed all the measurements in a given project. For instance, in Vitruvius (10.2.14):
He made wheels of about fifteen feet in diameter, and in these wheels he enclosed the ends of the stone; then he fastened 1/6th foot crossbars from wheel to wheel round the stone, encompassing it, so that there was an interval of not more than one foot between bar and bar.[5]

And outside of Vitruvius things like the vessel marked (*CIL* 8.24612):
46 + 1/2 + 1/12 modii[6]

Thus everything is proportional to the notional “foot”. But if all the measurements in a given domain are rendered this way, then nothing necessarily ties that ”foot” to any absolute standard. If there is no system of relations, individual units are freer to drift. I do not wish to overstate this point. First, one could in principle imagine a rigorously anchored system of unit-plus-fractions-and-multiples superficially resembling what we've just seen with *pedes* and *sextarii* (this, is after all, the way the modern SI metric system works). And, second, an order of magnitude is suggested by named units. But the co-existence of the two options (fractions and multiple units) is what suggests flexibility in the case of the lone unit. Why have the more complex system of compound measures as well, unless it is meant to express something different?

One might even try to attempt to extend the same logic to measures expressed in combinations of cubits, feet, palms, and digits. After all, Vitruvius explicitly defines them in terms of ratios with each other. Now, if all four of these units have absolutely fixed values, then by definition they stand in some ratio to each other, but Vitruvius stresses the simplicity of the ratio and the “fact” that it is the interrelationship which defines all the terms. Is it possible, then, that this superficially differing set of “cubit/foot/palm/digit” is precisely the same thing as “1.5 feet, 1 foot, 1/4 foot, 1/16 foot”? Perhaps it could have been, but in fact that seems unlikely to be the case. First, whatever might be the case with measurements of other quantities, here the actual body parts interfere with the abstraction and give an independent intuition of the value of each unit. Second, different authors and even different projects seem to privilege different units in the set. In surviving Roman practice, feet are probably more common than any of the others, as is certainly the case in Vitruvius, but overall, it is not clear which unit would be taken as the “base.”[7] Finally, there is the fact that a rich array of fractions and multipliers was always available. *Unciae* (twelfths of a foot) are functionally very similar to *digiti*; palms are in theory the same as a quarter of a foot; and a cubit could just as well be (and often is) expressed as a *sesquipes*. As in the more general case just discussed, the ongoing parallel existence of both framings suggest they operate differently, and the independent, bodily motivation of the cubit/foot/palm/digit series seems a natural explanation. The units exist independently, even if that is not often exploited.[8]

At any rate, let me turn to another of Vitruvius’ famous features I have already alluded to: modular design. Coulton 1989.85 draws an important distinction between the way that the notion of ”module” is used, at least some times, in Vitruvius and its use in much modern parlance:

> For Vitruvius and the Renaissance the module is a proportional concept, not one of standardised measurement, a point which may seem obvious, but which needs to be made clearly because modular design does not generally have that sense nowadays. In modern architectural parlance modular design means rather design in terms of units of standardised sizes, whether they are prefabricated concrete wall panels or factory-made kitchens cupboards.

Two points need to be made here. First, as Coulton himself point out, this narrower sense of ”modulus,” one that merely expresses proportionality, is not the only one in Vitruvius. The theoretical sense is not so strong as to guarantee technical use of the terms. Second, I would suggest that even if we restrict ourselves to the subset of usages identified by Coulton, we still do not quite reach pure proportionality. That might be better represented by something more prosaic like the formulas for mortar or paving cements (2.5.1; cf. 7.1.3):

> After slaking it, mix your mortar, if using pit sand, in the proportions of three parts of sand to one of lime; if using river or sea-sand, mix two parts of sand with one of lime.[9]

The ”parts” could be anything, and we could equally well start from either component or from the total amount we want to end up with. Nothing in the recipe suggest any kind of anchor, internal or external.

That is not the case for modules. The first, definitional use of *moduli* refers to them as based on elements (*membris*) of the construction (1.2.2):

"Quantity" refers to the selection of modules from the members of the work itself and, starting from these individual parts of members, constructing the whole work to correspond.[10]

Shortly thereafter Vitruvius turns to specific examples [1.2.4]:

In the case of temples, symmetry may be calculated from the thickness of a column, from a triglyph, or even from an *embater*; in the ballista, from the hole [for the torsion spring]...; in a ship, from the space between the oarmounts...; and in other things, from various members.[11]

The only case here in which the *modulus* might not be an actual object, but an abstract standard is the somewhat mysterious *embater*. In a later passage, and the only other instance of the word in this apparent sense in either language, Vitruvius seems to say that it is a Greek synonym for *modulus* (4.4.3, quoted below). But that reading is hard to understand etymologically. Additionally, if it really were a true synonym, it is also hard to understand how it can fit in this passage. If it is to be taken as "module" in general, it should have been the final default option. Instead it is just one of several options specifically for temples, while *membra* remain the general fall-back. While we do not have enough information to trace the evolution of the term, I imagine Coulton's (1989:86) suggestion must be at least roughly correct. The *embater* (or ἐμβάτης) would have been something like a step or stylobyte block (which would make etymological sense, as well as providing the required concreteness), and that unit would go on to become a common *modulus*, and perhaps even sometimes be used metonymically to mean *modulus*. Hence Vitruvius' later gloss would not be completely incomprehensible, even if we understand the words are not entirely synonyms.(4.3.3):

Let the front of a Doric temple, at the place where the columns are put up, be divided, if it is to be tetrastyle, into twenty-seven parts; if hexastyle, into forty-two. One of these parts will be the module (in Greek ἐμβάτης).[12]

To continue beyond the formal definition, let's look at the first major exploitation of the concept, the proportions of the Ionic temple facade. There we see precisely a real object that both takes on a privileged place in the scheme and sets a general scale for the project: the thickness of a column. The other entities are rendered as fairly simple fractions or multiples of this. The repetition of the term *modulus* as a unit and the simplicity of the fractions show that this is the conceptually basic unit. That is, it is not necessarily so different from the case of, say, "foot" with its multiples/fractions in cases where that allows for limited variability in the absolute length of the base unit. Here, of course, there is more (but not infinite) range for variation in the size of the base unit.

Not only is the *modulus* normally (perhaps always) a concrete thing, it is a thing of a particular kind of size. It is never the smallest unit of a construction and rarely is it the largest.[13] It is small enough to be grasped by a single human being, but also large enough that the likely margin of error in fabrication need not be catastrophic. This is a practical unit of measure. Note also that in at least some cases Vitruvius has to go out of his way to arrive at such a practical unit, even at the cost of some mathematical inelegance. To find the basic module for the eustyle temple he tells us to divide the length of the building into 11.5, 18, or 24.5 parts (3.3.7). But the geometric construction to do so would in fact involve dividing it into 23 or 49 parts, then pairing off most of those. Why not just let the 23rd or 49th part be the module? Because a 23rd or 49th part doesn't represent any important feature of the building. And the same argument holds for the systyle Doric temple described at 4.3.7.

As many have noted, even those computations work as neatly as they do only because there are different *moduli* for the Ionic and Doric orders: the column-width for the former, the trigylph-width for the latter. Wilson Jones (2001) has traced the Doric version to an early and authentic version of that specific design tradition. Nor do I think this is really a special case. There is perhaps evidence for the intercolumnation as another module in some contexts (3.2.5-6). And while the Tuscan order works numerically in the same way as the Ionic, the terminology is different. Vitruvius repeats the phrase *crassitudo* (*ima*). More generally, as has been well demonstrated, even Vitruvius' abstract terminology is not consistent. In addition to *modulus* and (perhaps) *embater* we also have frequent use of the phrase *rata pars*.[14] This kind of phenomenon is often attributed to Vitruvius' failure to reconcile his various sources. While that is undeniably a feature of Vitruvius' text, I would suggest that in this case the notion of "failure" begs the question a bit. If we look beyond temples, there are other modules necessarily incommensurable with those of any building: for instance, those of the catapults Vitruvius will go on to describe, or the of ships he does not. Uniformity would only be possible at the level of the module as a fully abstract notion of proportionality, and this does not appear to exist anywhere else any more than in Vitruvius' own text. Rendering all his sources in a uniform fashion would not have been mere reconciliation; it would have been a staggering theoretical advance.

The notion of design by proportion has, as I suggested before, considerable symbolic value for Vitruvius. As an organizing principle it provides some of the systematicity and predicability that mark out a domain of knowledge as an *ars* or τέχνη, from an aristocracy-friendly point of view.[15] To this extent it resembles similar aspects of the self-fashioning of, say, Quintilian or the Elder Pliny, making spaces for themselves as specialists useful to the imperial order.[16] At the same time, it also connects architecture to "higher" arts like mathematics and, through it, to the natural order of the universe. Proper building then has a function almost like Stoic philosophy—bringing human life into line with the broader order of things. But these symbolic functions do not require any particular connection between the theory in books and actual practice on the ground. And scholars have pointed to gaps between the two.[17] In the case of modularity, I will just mention Wesenberg's 1994 paper on its artificiality and ambiguity. Proportional composition is, at most, an idealization. But, I have tried to argue in this first section of this paper, that is not the whole story. There existed pragmatic as well as symbolic reasons for proportional measurement at the time, and aspects of Vitruvius' version of modular design already move away from purely mathematical elegance, and into a world shaped by real-world considerations.

I turn now to the second half of my argument. Here I want to look not at varieties of strongly proportional measurement, but at evidence for more firmly anchored metrological regimes.

The most obvious of these would be explicit measurement in specified numbers of specified units. These are common enough in *de Architectura*, but as I have already suggested, the meaning of these measurements is perhaps less clear than it might appear. A series of measurements all in terms of the same unit does not in itself hinge on appeal to an intersubjectively available standard for that unit, and in practice may only suggest an order of magnitude. This, as I have also suggested already, is a common feature of Roman metrology. What Vitruvius means by that style of measurement then remains ambiguous. Clearer, perhaps paradoxically, are the considerable number of places where Vitruvius specifies measurements in a range or as approximations, for instance:

The rise of such steps should, I think, be limited to not more than 3/4 foot (*dexante*) nor less than 5/6 (*dodrante*); for then the ascent will not be difficult. (3.4.4)[18]

or

On the top of the wall lay a structure of burnt brick, about a foot and a half in height, under the tiles and projecting like a coping. (2.8.18)[19]

In these cases, unless "foot" has a fairly precise meaning, there would be no reason to hedge by giving a range. This is especially true of the first passage where the specified range is quite small.

Another approach that suggests the constraints of absolute measurement is the use of combinations of units. As I have said, this is fairly *un*common in Roman metrology in general. They are less so in Vitruvius, and all but one case involves some combination of the digit/palm/foot/cubit series, which I have already touched on. The stepping in a theater is a good example (5.6.3):

The seats (*gradus*) on which the spectators sit are not to be less than a foot and a pal in height, nor more than a foot and six digits. Their width must not be more than two feet and a half, nor less than two feet.[20]

as is the water screw built around a beam as wide in inches as it is long in feet (10.6.1). One could also point to the sensitive relationship between feet and miles in the odometers Vitruvius constructs in 10.9, especially since the constructor and the eventual user or users of the information are presumably different people. For these units to be used in combination means that they, too, must exist independently.[21]

The same argument applies with even more force to passages (admittedly rare) in which Vitruvius combines different units of different dimensionality. The simplest instance is (7.8.2):

Four *sextarii* of [mercury], when measured and weighed, will be found to be one hundred pounds.[22]

but more expansively he offers two sets of correspondences between a linear measure and a weight. The first of these involves the weights of standard gauges of lead pipes and the second connects the weight of projectiles fired by a ballista to the diameter of the coiled spring that powers the device:

If the pipes are so-called "hundreds" [that is, according to Vitriuvius, rolled from a sheet 100 *digiti* across], they should weigh 1200 pounds each length; if eighties, 960 pounds; if fifties, 600 pounds; forties, 480 pounds; thirties, 360 pounds; twenties, 240 pounds; fifteens, 180 pounds; tens, 120 pounds; eights, 100 pounds; fives, 60 pounds. The pipes get the names of their sizes from the width of the plates, taken in digits, before they are rolled into tubes. (8.6.4)[23]

A ballista intended to throw a two-pound stone will have a hole of five digits in its frame; four pounds, six digits, and six pounds, seven digits; ten pounds, eight digits; twenty pounds, ten digits; forty pounds, twelve and a half digits; sixty pounds, thirteen and a half digits; eighty pounds, fifteen and three quarters digits; one hundred pounds, one foot and one and a half digits; one hundred and twenty pounds, one foot and two digits; one hundred and forty pounds, one foot and three digits; one hundred and sixty pounds, one foot and a quarter; one hundred and eighty pounds, one foot and five digits; two hundred pounds, one foot and six digits; two hundred and forty pounds, one foot and seven digits; two hundred and eighty pounds, one foot and a half; three hundred and twenty pounds, one foot and nine digits; three hundred and sixty pounds, one foot and ten digits.(10.11.3)[24]

There are a number of textual problems with particular numbers here, as well as a possible systematic calculation error on Vitruvius' part, but none of that is relevant here.[25] If Vitruvius can predict the weight of a pipe of a given diameter or calculate the appropriate spring size given the projectile weight, the units of distance and weight must both be well defined. I would particularly note the fairly subtle variations in spring diameter involved; the system seems to require considerable precision.

In most of the cases I have discussed to this point, modules aside, I have been inferring metrological theory from practice. How much external information, in the form of widely and precisely available standards, do we need to assume to make sense of the measurements Vitruvius speaks of? The last case I want to treat involves a more direct declaration on Vitruvius' part, a planned allometry. I borrow the term allometry from comparative anatomy, where it refers to differences in size between comparable parts of different animals (or certain other features like heart rates) that are not linearly proportional to the overall difference in size, for instance, the more robust skeletons of large animals compared to small ones (other things being equal), or babies' large heads relative to adults'.[26]

Though they have not attracted much attention as such, there are several instances of explicit allometry in *de Architectura*. Several of these are associated with Vitruvius' treatments of diminution of columns or doorways (4.6.1-2) or chaneling of volutes (3.5.7) or architraves (3.5.8).[27] Consider the following passage (3.3.12):

Moreover, the diminution in the top of a column at the necking seems to be regulated on the following principles: if a column is fifteen feet or under, let the thickness at the bottom be divided into six parts, and let five of those parts form the thickness at the top. If it is from fifteen feet to twenty feet, let the bottom of the shaft be divided into six and a half parts, and let five and a half of those parts be the upper thickness of the column. In a column of from twenty feet to thirty feet, let the bottom of the shaft be divided into seven parts, and let the diminished top measure six of these. A column of from thirty to forty feet should be divided at the bottom into seven and a half parts, and, on the principle of diminution, have six and a half of these at the top. Columns of from forty feet to fifty should be divided into eight parts, and diminish to seven of these at the top of the shaft under the capital.[28]

The adjustment itself is defined by a proportional factor (5/6, 11/13, 13/17), but how do we know what proportions to use? That hinges on the absolute side of the structure (15 feet or under; 15 to 20 feet; 20 to 30 feet). Similar procedures are also followed in the other descriptions of diminution at 3.5.7,8 and 4.3.10. Moreover, it is not restricted to height-related phenomena. Compare this passage on the proper proportions of the alae off of an atrium:

The alae, to the right and left, should have a width equal to one third of the length of the atrium, when that is from thirty to forty feet long. From forty to fifty feet, divide the length by three and one half, and give the alae the result. When it is from fifty to sixty feet in length, devote one fourth of the length to the alae. From sixty to eighty feet, divide the length by four and one half and let the result be the width of the alae. From eighty feet to one hundred feet, the length divided into five parts will produce the right width for the alae. (6.3.4)[29]

The ratio varies with the absolute value of the size of the atrium. Or in the country house, the "oil-room":

should be not less than sixteen feet wide, which will give the men who are at work plenty of free space to do the turning conveniently. If two presses are required in the place, allow twenty-four feet for the width. (6.6.3)[30]

Doubling the capacity increases the width, but does not double it. And the implicit formula for the spring size of the ballista we saw a moment ago appears to involve a cube root.

And in fact Vitruvius recognizes the phenomenon explicitly. Allometry does not get the prominent early placement of modularity, but it does come very near to forming the conclusion of the work, being discussed as part of the final section on defensive measures in war (10.16.5):

For not all things are practicable on identical principles, but there are some things which, when enlarged in imitation of small models, are effective, others cannot have models, but are constructed independently of them, while there are some [things] which appear feasible in models, but when they have begun to increase in size are impracticable, as we can observe in the following instance. A half inch, inch, or inch and a half hole is bored with an auger, but if we should wish, in the same manner, to bore a hole a quarter of a foot in breadth, it is impracticable, while one of half a foot or more seems not even conceivable.[31]

Allometric scaling, whether of size or heart rates or anything else, is largely a matter of the physics of the systems involved, for instance the fact that volume and surface or cross-sectional area cannot scale together. And that is of course what Vitruvius is getting at in his example of the auger.[32]

Besides the case of the ballista, most of the overt allometry in Vitruvius, however, is more indirect. Consider the explanations Vitruvius gives for modifications in the first place. At different points in book III he says:
3.5.9: For the higher that the eye has to climb, the less easily can it make its way through the thicker and thicker mass of air. So it fails when the height is great, its strength is sucked out of it, and it conveys to the mind only a confused estimate of the dimensions.[33]

3.3.12 These proportionate enlargements are made in the thickness of columns on account of the different heights to which the eye has to climb. ... if we do not gratify its desire for pleasure by a proportionate enlargement in these measures, ... a clumsy and awkward appearance will be presented to the beholder.[34]

Ignoring the question of precise consistency here, the interesting thing for me is the shared focus on impression over fact, and in particular the introduction of an audience, made even more explicit at 6.2.2:[35]

The look of a building when seen close at hand is one thing, on a height it is another, not the same in an enclosed place, still different in the open, and in all these cases it takes much judgment to decide what is to be done. The fact is that the eye does not always give a true impression, but very often leads the mind to form a false judgment [explicitly connected to *symmetria* in previous section][36]

In one sense, a Doric temple could really be the product of dimensionless proportionality. A souvenir model of the Parthenon could follow the proportions of the real one exactly. But that would, of course, be a toy, not a temple. The difference is that while columns, capitals, and triglyphs can all scale together, there is a mostly unspoken element that fixes the rest fairly narrowly: the human users of the structure. Most of them are around the same size, and interact with it in broadly similar ways.

He does not give as full an explanation of most of the non-altitude examples, but similar considerations would seem to account for the room with the olive presses as well. Unlike, say, amphorae, working men do not fill the entire room. They are explicitly moving through the space. With two presses, the two teams can share each other's empty space, at least to an extent. Similarly, to refer back to the range of possible dimensions for steps, those assume people of a given size approaching the temple in a predictable way. He is explicit, however, when it come to the number of flutes on interior vs. exterior columns (4.4.3):
The reason for this result is that the eye, touching thus upon a greater number of points, set closer together, has a larger compass to cover with its range of vision.[37]

I mentioned above Wesenberg's argument for the largely theoretical character of Vitruvius' modules. More generally, there has been considerable scholarly discussion over where, if at all, various bits of Vitruvius' content can be located in time or place or in theory or practice.[38] At a minimum we can say there are many elements that do not reflect how things were built in Vitruvius' day and time. I do not quite mean to add to the list of parallels or of non-parallels of this sort, which would require archeological expertise I lack. Rather I want to suggest real-world constraints on Vitruvius' outlook that are of a more generic sort. I have tried to show these traces of the real world in Vitruvius's work in two senses. In the first part of the paper, I argued that even when he was operating with systems of proportion, he did so in ways that had as much to do with the avoidance of fully standardized measurements as they did with display value of a formalized, mathematical imagination. And in the second half I argued that in places, even this was not enough. Vitruvius built real buildings (and catapults and the rest), and those come with allometric constraints. In particular they were built for human beings, and that checked the free play of proportion. These constraints do not, of course, magically give Vitruvius the power to measure in a more standardized way than he had elsewhere, but they do drive him to use what resources the metrological culture provided to fix measurements. Vitruvius is famous for the abstraction of "Vitruvian man," but he operated in an environment constrained by building things for the use of real men, of real human beings. That, I have argued is the constraint on his metrology. That is the limit of proportion.

Works Cited

Coulton, J. 1989. "Modules and Measurements in Ancient Design and Modern Scholarship," in H. Geertman and J. de Jong, edd., *Munus Non Ingratum*. Leiden. 85-89.

Cuomo, S. 2007. *Technology and Culture in Greek and Roman Antiquity*. Cambridge.

Drachmann, R. 1954. "Remarks on the Ancient Catapults," in *Actes du VIICongrès International d'Histoire des Sciences*. Paris. 279-82.

Ferri, S. ed., trans., comm. 1960. *Vitruvio: Architettura (dai libri I-VII)*. Rome.

Gould, S. 1966. "Allometry and Size in Ontogeny and Phylogeny," *Biological Reviews* 41.587-638.

Gros, P. 1975. "Structures et limites de la compliation vitruvienne," *Latomus* 34.986-1009.

———, ed., trans., comm. 1990. *Vitruve: De l'architecture, livre III*. Paris.

Marsden, E. 1971. *Greek and Roman Artillery: Technical Treatises*. Oxford.

***Le projet de Vitruve. Objet, destinataires et réception du De Architectura. Actes du colloque international* (= Coll. de l'École Française de Rome 192).**

Riggsby, A. 2007. "Guides to the Wor(l)d," in J. König and T. Whitmarsh, edd., Orde*ring Knowledge in the Roman World*. Cambridge. 88-107.

Ulrich, R. 2007. *Roman Woodworking*. New Haven.

Wallace-Hadrill, A. 1994. *Houses and Society in Pompeii and Herculaneum*. Princeton.

Wesenberg, B. 1994. "Die Bedeutung des Modulus in der vitruvianischen Tempelarchitektur," in *Le projet de Vitruve*. Rome. 91-104.

Wilson Jones, M. 2000. *Principles of Roman Architecture*. New Haven.

———. 2001. "Doric Measure and Architectural Design 2: A Modular Reading of the Classical Temple," *AJA* 105.675-713.

1 I would very much like to thank the organizers for their very kind invitation to present my research at the original conference (which was both well conceived and well executed). I would also like to thank the other attendees for the lively discussion and Prof. Gros for his gracious commentary. Translations are drawn, with very slight alterations, from M. H. Morgan's version (Harvard UP 1914).

2 Corpus enim hominis ita natura composuit, uti os capitis a mento ad frontem summam et radices imas capilli esset decimae partis, item manus palma ab articulo ad extremum medium digitum tantundem, caput a mento ad summum verticem octavae, cum cervicibus imis ab summo pectore ad imas radices capillorum sextae, <a medio pectore> ad summum vertices quartae.

3 3. 2.5, 6; 3.2, 4, 6, 7, 10-11; 4.1, 3; 5.1-3, 5-7, 9-13; 4.1.1, 6-8, 11-12; 3.2-8; 4.1; 6.1-6; 7.1-5; 8.1-3; 5.1.2-5; 6.5-6; 9.2-4; 10.4-5; 11.2; 12.2-3; 6.3.3-8; 8.6-7; 7.1.3, 5; 8.6.14; 9.pr.8; 7.1.

4 Other instances include 3.5.14; 4.3.9; 5.5.2-4; 5.3.4; 5.7.1-2; 5.6.1, 3; 6.8.7; 9.7.2-6; 10.6.1-2.

5 Rotas enim circiter pedum XV fecit et in his rotis capita lapidis inclusit, deinde circa lapidem fusos sextantales ab rota ad rotam ad circinum compegit, ita uti fusus a fuso non distaret pedem esse unum.

6 Modii...XLVIS- [The character rendered here as a conventional S is actually mirror-reversed.]

7 Book 10 contains a disproportionate number of measurements in cubits. I suspect this is a matter of calquing on specialized Greek sources for these topics.

8 A more literary point arises from these considerations. In the passage I have already referred to several times, Vitruvius attributes his canon of proportions not just to any person, but to a *hominis bene figurati* (3.1.1). Gros 1990.LIV, 61-3 has already noted one slippage here; Vitruvius represents a rule of fine art as a fact of nature. I would add that the slippage causes Vitruvius further difficulties. How do we identify the "properly shaped" person? There is no clear criterion beyond (circularly) adherence to the canon. Moreover, we later learn that nature has provided us with other canons. The 6:1 ratio that characterized the *homo bene figuratus* is in fact limited to the *vir bene figuratus*. Vitruvius justifies slimmer ratios of height to breadth in the original Ionic and Corinthian columns by appealing to the forms, of women and maidens (4.1.7-9), respectively. That is to say nature is diverse and complex. Canonical proportions are perhaps "natural" in the sense of being attested somewhere in nature, but to claim that one is any more natural than some (perhaps any) other ones requires human intervention. Vitruvius' insistence on the naturalness of these particular ratios smacks of protesting too much. This will be relevant later to the question of what Vitruvius gains for himself by these displays of proportionality, but here I just note that those gains account for his emphasis on the relatedness of those units. This passage is not good evidence for their actual equivalence in that way.

9 Cum ea erit extincta, tunc materia ita misceatur, ut, si erit fossicia, tres harenae et una calcis infundatur; si autem fluviatica aut marina, duo harenae una calcis coiciatur.

10 Quantitas autem est modulorum ex ipsius operis <membris> sumptio e singulisque membrorum partibus universi operis conveniens effectus….

11 Uti in homonis corpore e cubito, pede, palmo, digito ceterisque particulis symmetros est eurythmiae qualitas, sic est in operum perfectionibus. Et primum in aedibus sacris aut e columnarum crassitudinibus aut triglypho aut etiam embatere, ballista e foramine, quod Graeci *peritreton* vocitant, navibus interscalmio, quae *dipechyaia* dicitur, item ceterorum operum e membris invenitur symmetriarum ratiocinatio.

12 Frons aedis doricae in loco, quo columnae constituuntur, dividatur, si tetrastylos erit, in partes XXVII, si hexastylos, XXXXII. Ex his pars una erit modulus, qui Graece *embater* dicitur, cuius moduli constitutione ratiocinationibus efficiuntur omnis operis distributiones

13 Wilson Jones 2000.233n23 puzzles over why there are no large modules with networks of fractions for subordinate units, which would be mathematically equivalent to what we actually find. What follows here and at the end of the paper attempts to answer that question.

14 1.2.4; 2.8.8; 3.pr.4, 1.9, 3.11, 5.8; 4.4.2, 4.4; 5.3.4; 6.2.1, 3.6.

15 Cuomo 2007.7-40 on this aspect of *ars*/τέχνη. While her discussion is formally limited to Athens, nearly all of it applies well to Rome.

16 Riggsby 2007.105-6.

17 For instance, see Wallace-Hadrill 1994.10-22 or the contributions to *Le Projet de Vitruve* (1994) by Frey, Geertman, Tehodorescu, and Tosi.

18 Crassitudines autem eorum graduum ita finiendas censeo, ut neque crassiores dextante nec tenuiores dodrante sint conlocatae; sic enim durus non erit ascensus.

19 Summis parietibus structura testacea sub tegula subiciatur altitudine circiter sesquipedali habeatque proiecturas coronarum.

20 Gradus spectaculorum, ubi subsellia componantur, gradus ne minus alti sint palmopede, <ne plus pedem> et digito sex; latitudines eorum ne plus pedes duo<s> semis<semque>, ne minus pedes duo<s> constituantur.

21 Other examples may be found at 5.6.3; 7.1.3, 6-7; 7.4.2; 8.5.2; 10.2.8, 11.3, 13.4-5, 15.5-7, 16.4, 10.6.1.

22 Id autem cum sint quattuor sextariorum mensurae, cum expenduntur, invenientur esse pondo centum.

23 Fistulae ne minus longae pedum denûm fundantur. Quae si centenariae erunt, pondus habeant in singulas pondo MCC; si octogenariae, pondo DCCCCLX; si quinquagenariae, pondo DC; quadragenariae pondo CCCCLXXX; tricenariae pondo CCCLX; vicenariae pondo CCXL; quinûm denûm pondo CLXXX; denûm pondo CXX; octonûm pondo C; quinariae pondo LX.

24 Nam quae ballista duo pondo saxum mittere debet, foramen erit in eius capitulo digitorum V; si pondo IIII, digitorum sex, VI, digitorum VII; decem pondo digitorum VIII; viginti pondo digitorum X; XL pondo digitorum XIIS≣; LX pondo digitorum XIII<I> et digiti octava parte; LXXX pondo digitorum XV; CXX pondo I pedis et sesquidigiti; C et LX pedis I≣; C et LXXX pe<di>s et digiti V; CC pondo pedis et digitorum VI; CC et X<L pondo> pedis et digitorum VI; CCC <pondo>, pedis IS.

25 Drachmann 1954, Marsden 1971.198-200, Gros 1975.997-8.

26 See Gould 1966 for a survey.

27 Cf. also 5.5.2-3 (also geometrical), 4.4.2, 6.3.4-6, 6.6.3

28 Contracturae autem in summis columnarum hypotracheliis ita faciendae videntur, uti, si columna sit ab minimo ad pedes quinos denos, ima crassitudo dividatur in partes sex et earum partium quinque summa constituatur. Item quae erit ab quindecim pedibus ad pedes viginti, scapus imus in partes sex et semissem dividatur, earumque partium quinque et semisse superior crassitudo columnae fiat. Item quae erunt a pedibus viginti ad pedes triginta, scapus imus dividatur in partes septem, earumque sex summa contractura perficiatur. Quae autem ab triginta pedibus ad quadriginta alta erit, ima dividatur in partes septem et dimidiam; ex his sex et dimidiam in summo habeat contracturae rationem. Quae erunt ab quadraginta pedibus ad quinquaginta, item dividendae sunt in octo partes, et earum septem in summo scapo sub capitulo contrahantur

29 Alis dextra ac sinistra latitudinis, cum sit atrii longitudo ab XXX pedibus ad pedes XL, ex tertia parte eius constituatur. Ab XL ad pedes L longitudo dividatur in partes tres s<emissemque>, ex his una pars alis detur. Cum autem erit longitudo ab quinquaginta pedibus ad sexaginta, quarta pars longitudinis alis tribuatur. A pedibus LX ad LXXX longitudo dividatur in partes quattuor et dimidiam, ex his una pars fiat alarum latitudo. A pedibus octoginta ad pedes centum in quinque partes divisa longitudo iustam constituerit latitudinem alarum. Trabes earum liminares ita altae ponantur, ut altitudine latitudinibus sint aequales.

30 Latitudo eius ne minus pedum senum denum; nam sic erit ad plenum opus facientibus libera versatio et expedita. Sin autem duobus prelis loco opus fuerit, quattuor et viginti pedes latitudini dentur.

31 Non enim omnia eisdem rationibus agi possunt, sed sunt alia, quae exemplaribus non magnis similiter magna facta habent effectus; alia autem exemplaria non possunt habere, sed per se constituuntur; nonnulla vero sunt, quae in exemplaribus videntur veri similia, cum autem crescere coeperunt, dilabantur. Ut etiam possumus hic animum advertere. Terebratur terebra foramen semidigitale, digitale, sesquidigitale. Si eadem ratione voluerimus palmare facere, non habet explicationem, semipedale autem maius ne cogitandum quidem videtur omnino.

32 Ulrich 2007.30 confirms that low-velocity ancient drills could not be scaled up in size this way.

33 Quo altius enim scandit oculi species, non facile persecat aeris crebritatem, dilapsa itaque altitudinis spatio et viribus, extructam incertam modulorum renuntiat sensibus quantitatem.

34 Haec autem propter altitudinis intervallum scandentis oculi species adiciuntur crassitudinibus temperaturae. Venustates enim persequitur visus, cuius si non blandimur voluptati proportione et modulorum adiectionibus, uti quod fallitur temperatione adaugeatur, vastus et invenustus conspicientibus remittetur aspectus.

35 See Gros 1990.xxxi on audience.

36 Alia enim ad manum species videtur, alia in excelso, non eadem in concluso, dissimilis in aperto, in quibus magni iudicii est opera, quid tandem sit faciundum. Non enim veros videtur habere visus effectus, sed fallitur saepius iudicio ab eo mens.

37 Hoc autem efficit ea ratio, quod oculus plura et crebriora signa tangendo maiore visus circuitione pervagatur.

38 See n.22 above.