The tools of Hues Libergier

Adapted from *Architectural Theory Review*, ii 1997, 142-149.

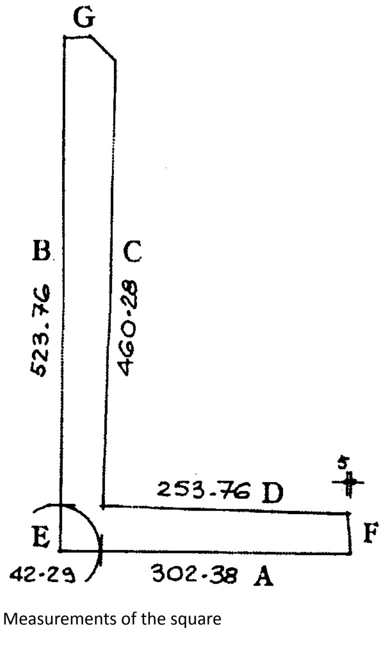
The tomb of Hues Libergier in Reims cathedral

The tomb of Hues Libergier is a rectangular slab of limestone now attached to the north wall of the Reims cathedral transept. Such a tomb for a master mason is unique before the fifteenth century.[1] Inscribed on it is one of the few surviving sets of master's tools from the thirteenth century, or before – his rod, square and proportional dividers.[2] These three instruments were all he needed to design and control the construction of cathedrals and fortresses and palaces and the myriad elements in them – including beams and arches, the complex stones that fitted like a Japanese puzzle-cube into stone vaults and the sinuous magic of window tracery.[3] With them he created the templates the carvers used for the simplest blocks and those that were curved in more than one plane simultaneously.[4]

The three tools are incised into the stone, and the incisions filled with strips of lead with an average thickness of 4 mm. I measured the tools carefully to both sides of the lead, to determine whether the inner or outer edges of the lead, or some place in between, marked the outline of the tool. I listed the ratios between each group of measurements to see if one seemed more appropriate than another. Three items convinced me that the outer edge of the lead coincided with the original outline of the tools.

Firstly, the outer edges of **the square**, B and A in the figure, revealed a ratio of 1.732:1, or √3:1, whereas their inner edges gave a meaningless 1.752:1.[5] This, then, may be the primary ratio used by Libergier, or perhaps only the ratio he used on whatever he was working on when he died,

Secondly, the overall length of **the rod** was precisely three times B if measured to the outside of the lead, but there were no relationships when the inner faces were taken.



Measurements of the square

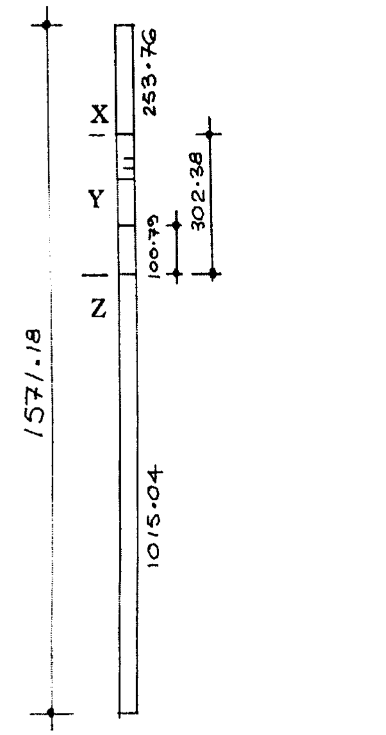
Thirdly, the upper subdivision of **the rod** X is one quarter of the lower section Y in the upper figure, and equals D only when taken to the outside of the lead.

I am prepared to take it, on this evidence and on the intimate relationships every tool has to every other, that the incisions on this tomb were of Libergier's actual tools, laid onto the stone and their outlines inscribed. Nancy Wu has argued that this would not be the case as the size of the master himself is somewhat too large for a medieval man (an assumption) and that the model of the church that he holds is symbolic (which would be irrelevant in relation to the tools themselves).[6]

The largest measurements are those of the stone slab into which the incisions have been made. It measures 2,740 mm high and is half as wide. This is exactly the ratio of 2:1.

The next largest is **the rod** in his hand that measures 1,571 mm in length.

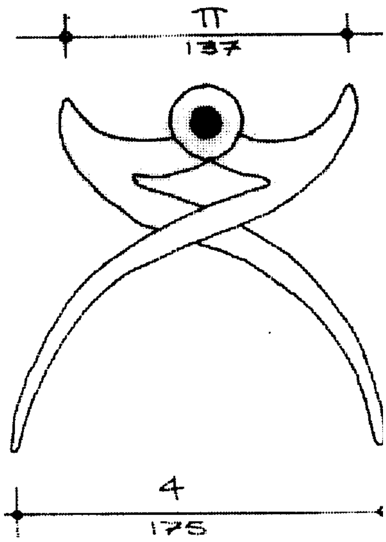
As there are small differences between the measurements and the calculations, I had to determine an 'ideal' length which could be calculated mathematically from the ratios and yet remain close to the actual.[7] To do this I combined the measurements of the tomb slab, the square and the rod, and divided these by the sum of the numerical ratios between them. The ideal measurements are noted on the drawings. Considering that there is less than a millimetre between the ideal lengths and the measurements, they are probably precisely those used by Libergier himself at the time the tomb was prepared.[8]



The rod as marked on the tomb. It is almost 4:7 to the height of the slab, ideally 1,568-2,743mm.

I shall continue to work with lengths to parts of a millimetre, unreal as this may be. Even though people of the thirteenth century could not have obtained this degree of accuracy, it is the only way to ensure that all the interlocking ratios can be calculated so that we may check to see that they fit the tools as measured. We have to be more accurate in our calculations than they were in either cutting or in marking the templates. Maintaining consistently small tolerances between the ideal and the actual is the only assurance we have that the sizes and the ratios they incorporate were close to those used by the master.

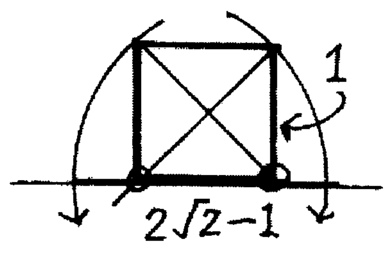
On the bottom right of the tomb is a pair of proportional dividers, right, that preserve the same ratio whatever opening is set. Simply by setting one pair of points along a length the other pair will always mark the same proportion. Libergier's are set to the ratio of 14:11, which is a close approximation to 4:π. This ensures that the circumference of a circle with diameter fourteen will equal the perimeter of a square with sides eleven.[9] It is the formula for squaring the circle, and useful in building work for it produces a cylindrical shafts with the same area as a rectangular one, thus converting, say, a pilaster into a drum. Philosophically, the concept of squaring the circle has intrigued people for thousands of years. Libergier may have used it to translate a host of circular mouldings, like shafts and piers, into their rectangular equivalents. As incised on the tomb the larger spread has been set at one third of B on **the square**.



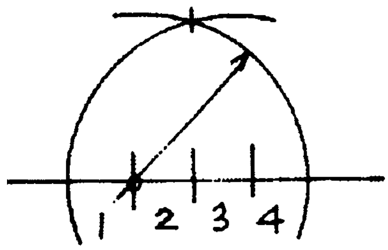
The dividers as marked.

The rod in Libergier's hands has rather curious subdivisions. The lowest section, Z, is the longest. The middle section, Y, is divided into three parts, which may have been equal but are inaccurately incised as Libergier's fingers get in the way.[10] The measured dimensions for X, Y and Z were 254 mm, 203 mm and 1,014 mm. The first equals D, the second is the same as A and the third is four times the upper section X.

There are *ad quadratum* ratios in **the rod**: the full rod relates to X+Y as 2√2:1, following which X+Y:Z forms the auron which is important in setting out vaults, the most difficult task in medieval masonry, bottom-right.[11] The



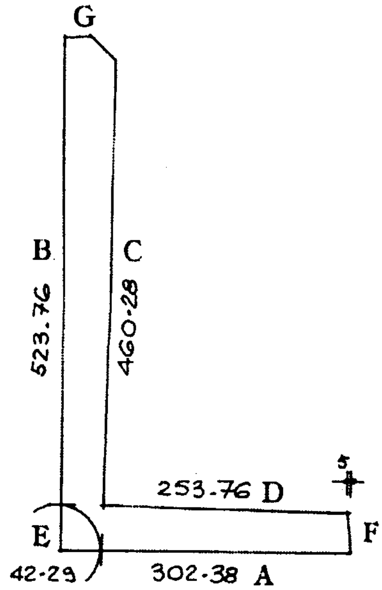
ratio is used to set out arches, as the height of a third point arch (in which the base is divided into four parts and the centre for the arch taken from the circles on both the third points) is 2√2 times each part, illustrated right. The ratios needed for the fourth, fifth, sixth and seventh point arches form an interesting additive series which can be calculated using an Archimedean spiral constructed with a compass and square.[12]



Possible setting out for centres of pointed arches

Laying out vaults, like many other parts of the building, was done full-size. If the church was large enough a film of plaster was flooded onto the floor and the design was laid out on it. There was little need for calculations as they did not possess rulers or tape measures as we know them, but set out their projections geometrically onto the plaster, needing only the tools marked on this tomb, be they arches or ribs, flying buttresses or tracery.

The third tool, the square, is marked on the lower left of the tomb. Its sides are not parallel, but are inclined at about 1° to one another, right. This intriguing device is shown in many medieval drawings, including Villard de Honnecourt's sketchbook, but the purpose of the inclination is not described.[13] Both the outer and inner sides are set at 90° to one another. For the outer pair the idealised dimensions are 523.76 mm and 302.38 mm which forms the ratio of √3:1 - precisely. The length of B is famous historically as the Royal Cubit from which the Ghiza pyramid was built.[14]



Measurements of the square

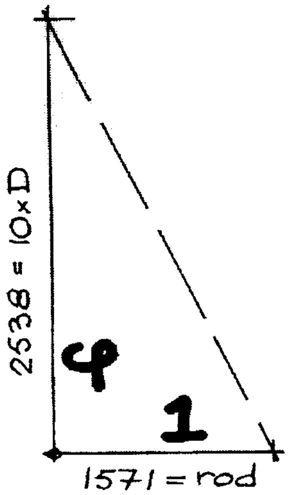
The inner sides are also at right angles to one another and are set out as tangents to the arc E. The radius of this arc is 42.29 mm, which is one sixth of D. The end of the blade (the longer arm) is wider towards the top, while the end of the tongue is splayed inwards 5 mm. Not having the square ends suggests that the lengths of the inner sides C and D are important. They are in the ratio of π:√3.[15] And across the square, A and D relate, though not with quite the same accuracy, as 6:5.

Libergier's tomb is unique in giving us a complete set of tools used by one master that were designed to be used together. We do not have the 'human provenance' for any other medieval tools that would permit this sort of analysis. The following connections between the rod, the square and the proportional dividers suggest how they could have been intended to be used together. Let us make the attempt to understand how they may have supplemented each other in daily use.

Firstly, the square is linked to the dividers through the inner sides, for the √3 ratio connects the outer sides and the π ratio with the dividers. This would have allowed the master to calculate his structural sizes *ad triangulum* from the outside of the square and transform straight-sided figures into circular ones using the inside of the square and the dividers.

Secondly, the rod relates to both sides of the square and therefore to the √3 and π ratios. There are three connections: multiply the Royal Cubit B by 3 for the length of the rod, the inner side D equals X and so equals one quarter of the lower section Z, and lastly the rod also equals 5 times D+A.

Thirdly, if we draw the triangle, right, and make one side 2,538 mm, or ten times D, and the other 1,571 mm from the rod, then this triangle has the ratio of 1:φ to an accuracy of a millimetre.



Relationship between the rod and the square

Fourthly, the square and the dividers complement one another, for if our base measurement is A, the triangle on that base gives √3 for B. If we expand B using the proportions of the inner sides (π:√3) we geta length of 950 mm. Set the smaller opening of the dividers to one quarter of this and the larger opening marks the base length we started with. We can calculate this circular argument algebraically, but to demonstrate it geometrically with dividers is quite an astonishing and unexpected experience.

'Circularity' is a process that seems to complete a geometric process that has followed certain guidelines. These guides have turned up in all the thousands of geometric studies I have made. There are three: that more than one ratio must be used; they should be mathematically irreconcilable; and the first step has to be mirrored in the last.[16] Here Libergier uses π and $\sqrt{3}$, which are mathematically irreconcilable, and starts with a distance and returns at the end of the sequence to an subpart of the first step. It is a circular model that was also described in contemporary booklets.[17]

It has always seemed to me that this technique was designed to authenticate the steps employed in the geometry. When I studied medieval philosophy, the processes used by the masters became a lot clearer. In philosophy opposing views from biblical and similar sources that appear contradictory are argued through until a reconciliation is reached in which the truth in both can be clearly stated. The methods common to both disciplines are readily recognised.

One other small matter: the inches marked on a rod or square could be used to cut angles and bevels in timber and stone, for a square mitre can be formed by laying twelve inches along the blade and five up the tongue, and a hexagonal mitre by laying twelve and seven. For the length of hips, rafters and other roofing members, all of which change with the pitch of the roof, such a square would be invaluable.[18]

Their ability to use these instruments and to make complex calculations should not surprise us, for they have ancient origins. Euclid was called 'the father of masonry' and Pythagoras and Boethius were called the originators of proportion. Medieval geometric methods show that the masters understood vectors, inclined thrusts and the quantification of loads. In the twelfth century Domincus Gundissalinus wrote a treatise on calculations for surveyors, with devices for stonemasons and carpenters.[19] On the Chartres west front among the figures representing the two Liberal Arts, geometry and arithmetic were placed at the highest point, possibly echoing Augustine who had stated that "God had made the world in measure, number and weight."

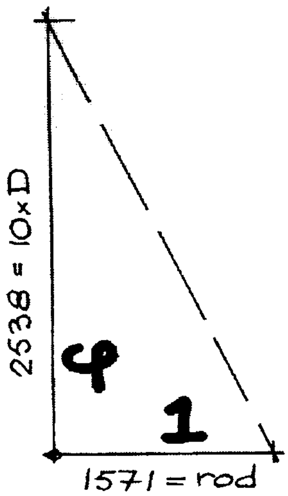
The lengths of the rod and the blade of the square seem the most important dimensions as one is three times the other, and (as I shall describe) a multitude of lengths and ratios stems from them. I would therefore presume that the cubit of 523.73 mm may have been his major measure. As the cubit is usually 1½ feet, the foot would be 349.17 mm, suggesting that the larger opening of the dividers had been set at half this foot.

In a parenthetical aside, Flinders Petrie and others have calculated the Egyptian Royal Cubit at between 519 and 524 mm. Even closer, Petrie showed that the cubit expands to form the Ater of 12,000 cubits. He measured this between stone stelae on the road from Memphis to Faium at 6,280 meters, from which he calculated the cubit at 523.33 mm.[20] It seems extraordinary that Libergier's cubit should be identical to one possibly used in Egypt almost 4000 years earlier. This again demonstrates the longevity of certain measures.

There are two other connections with Ghiza that are most intriguing. Firstly, 440 of these cubits were used to set out each side of the great pyramid and 280 the height, which is half the proportion Libergier used in his dividers and can be used to generate π. Secondly, the $1{:}\varphi$ ratio used between the rod and the square is the proportion between the base of the pyramid and the apothem, or length up the inclined side from the base to the apex.

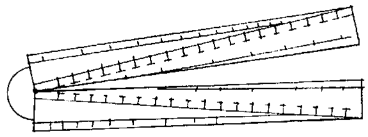
We should not get too excited about the Egyptian connections, for though the 523 mm cubit has been known for over thousands of years, it was also used in Irish field systems, bronze rods from Harrappa in northern India and in Mexico. It is found in English churches from pre-Conquest times, and it lasted well into modern times with the Maltese Qasba and the Venetian foot, to mention only a few.[21] Also, the league, mentioned in the Domesday Book as the most common long measure used in the eleventh century, contained exactly 7,000 Royal feet. It is not the measure itself that is a thing of wonder, but its millenial-long constancy.

Returning to Libergier, it is often said that the inclined sides of the square were used to set out the angled ends of arch voussoires. But the inclination in all surviving squares is never more than 1.5°, which would have limited arches to 40 voussoires – too few if set over a wide nave, and too many if set over a doorway. The inclination may have been set out using the long side of the triangle we saw earlier, right, which contains 60 inches of the 42.29 mm used at E. One of these inches marking the width would have established a line inclined at one inch in five feet, or one in 60.[22]



Relationship between the rod and the square

The purpose of the inclination (and if there is a 'secret' among the Masters, this splayed square could be it) may be traced among seventeenth century instruments called 'sectors'. These were squares with parallel sides, but with lines incised on them that were not parallel to the sides, lower right. Calculations in gunnery, surveying and navigation were performed on them using a straight edge and proportional dividers.[23] The first sector is attributed to Galileo around 1598 and log scales were included in 1624. Three years later an Italian architect made one to calculate the proportions of the five classical orders.[24] They were precursors to the slide-rules of my childhood.


Seventeenth century Sector.

Not only do the inclined lines suggest that the master's square was the origin of the sector, but so does its name. In Italian it was *compasso di proporzione*, and in the French *compas de proportion.* The methods used to calculate with sectors are complex, and though too detailed to discuss here suggest similar techniques could have been used between the inclined legs of the square.[25] From the twelfth century onwards sectors were needed to make calculations for land surveying, vault projections and for determining heights from a distance. Squares are still used today in timber roofing construction for calculating cuts for different roof forms, though modern trusses have made this all but obsolete.

On the other hand, Bill Huff suggested in a letter from Buffalo that "the inside angle actually has nothing to do with the outside as it might be visually advantageous to have them not parallel, as in practice on site the eye can more easily distinguish two non-parallel angles. The non-parallel angles became an affectation in time – a trademark."

The master's tools were the indispensable vehicle for translating skill into action. However, it was in the end, as Lon Shelby wrote, "not the sophistication of the tools themselves, but the skill and ingenuity displayed in the use of those tools that made possible the great achievements of the medieval masons."[26]

I like to think that the use of computers won't blind us to the extraordinary ingenuity needed to design and construct complex buildings, nor limit our appreciation of their great skill in finding ways to do so.

1. The earliest are Roman masons' tombs and bronze tools, mainly compasses.
2. Bernard G. Morgan, *Canonic design in English medieval architecture,* Liverpool, 1961. Morgan describes a number of metal squares, one of which has splayed sides of 1° 30' 10".
3. Lon Shelby, "Medieval masons' tools; II compass and square", *Technology and Culture,* vi 1965, 236-248; "Setting out the keystones of pointed arches: a note on medieval 'Baugeometrie'", *Technology and Culture*, x 1969, 537-548 and "The

geometrical knowledge of mediaeval master masons", *Speculum*, xlvii, 1972, 395-421. Also François Bucher, "A rediscovered tracing by Villard de Honnecourt", *The Art Bulletin*, lix 1977, 7-50; Robert Branner, "Villard de Honnecourt, Archimedes and Chartres", *Journal of the Society of Architectural Historians, x*ix 1960, 91-96 and Carl Barnes jr., "The Gothic architectural engravings in the cathedral of Soissons", *Speculum*, xlvii 1972, 60-64.

4. John James, *The Template-makers of the Paris Basin,* Leura, 1989.
5. This analysis used the list of over 600 possible ratios, John James, *The Ratio Hunter*, Dooralong, 1978.
6. Nancy Wu, "Hughes Libergier ands his Instruments", *Avista Forum*, xi 1999.
7. For 'idealising' se John James, "26 Measuring and extracting geometry", *In Search of the unknown in medieval architecture,* 2007, Pindar Press, London.
8. The 'ideal' length of A would have been 302.38 mm, whereas it measures 302, and the ideal of B would be 523.73 mm compared to 524. Similarly, D would be 253.76 instead of 254 mm and the rod 1,571.18 mm instead of 1,571 mm.
9. One gap measures 175 mm, where one third of B would be 174.59 mm. The smaller measures 137 mm when this ratio would give 137.12 mm.
10. One of these parts is halved and halved again into twelve divisions of Y of 25.20 mm.
11. Kenneth Conant, "Medieval Academy excavations at Cluny IX: systematic dimensions in the building", *Speculum,* xxxviii 1963, 1-43.
12. This series is $\sqrt{3}$, $\sqrt{8}$, $\sqrt{15}$, $\sqrt{24}$, $\sqrt{35}$ and $\sqrt{48}$. Branner, "Villard".
13. Bucher, *Architector*. In the examples it would make no difference whether the square had parallel or inclined sides, being to measure offsets in V39 and shaft diameters in V40. François Bucher, *Architector. The lodge books and sketchbooks of medieval architects,* New York, 1979.
14. Flinders Petrie, *The Pyramids and the Temples of Gizah*, London, 1883; Peter Tomkins, *Secrets of the Great Pyramid,* London, 1973.
15. The calculated length of C is 460.28 mm where it measures 461 mm.
16. Discussed in John James, "26 Measuring", *In Search of the unknown in medieval architecture*, 2007, Pindar Press, London..
17. John James, "Gothic pinnacles", *The Architectural Association Quarterly*, xi 1979, 55-59; John James, "32 Discrepancies", *In Search of the unknown in medieval architecture*, 2007, Pindar Press, London. The clearest examples are those in John James, *The contractors of Chartres,* Wyong, ii vols. 1979-81
18. Fred Hodgson, *ABC of the Steel Square*, Chicago 1928.
19. François Bucher, "The Dresden sketch-book of vault projection", *Acts of the 22nd.- International Congress of Art History*, Budapest, 1972, 527-537.
20. Flinders Petrie, "Measures and weights, ancient and modern," *Encyclopedia Britannica,* 1929.
21. The Irish acres has sides of 2,880 English feet which is 2,500 Royal Feet. For Harappa: Stuart Piggott, *Prehistoric India*, London, 1962; for Mexico: Petrie, "Measures and weights"; and G. B. Grundy, "The old English Mile and the Gallic league," *The Geographical Journal*, March 1938. Was this the unit Galileo used when he calculated the diameter of the moon at 2,000 miles, each of 5,000 feet of 347.7 mm? Galileo Galieli, *Dialogue of the Great World System,* Chicago, 1953, 106.
22. One in sixty is 0°57.3', one in 48 is 1°11.6' and one in 36 is 1°35.5'. This makes the difference between F and E precisely 5.3 mm (it measure 5 mm) and between H and E 8.73 mm (it measures 9 mm).
23. Maya Hamble, *Drawing Instruments,* 1580 – 1980, London, 1988.
24. Revisi Bruti, *Archiesto per formar con facilita li cinque ordini d'architettura,* Vincenza, 1627.
25. Thomas Hood, *The making and use of the geometrical instrument called a sector,* 1958; Jacob Leopold, *Theatrum arithmetico geometricum, London,* 1727, lists twenty functions that could be performed with a sector. Nicolas Bion, *The construction and principal uses of mathematical instruments,* trans. Edmund Stone, 1758.
26. Shelby, *Medieval masons' tools,* 248.