Chapter 5

Geometry of Conquest

The *Colonia*

A crucial part of gaining and keeping empire is to snare new lands in a net of measurement. To truly acquire a land a new government must send in teams of surveyors to fix key reference points and to begin the process of parceling the earth into organized grids of ownership as well as to lay down a web of roads to join these parcels together.

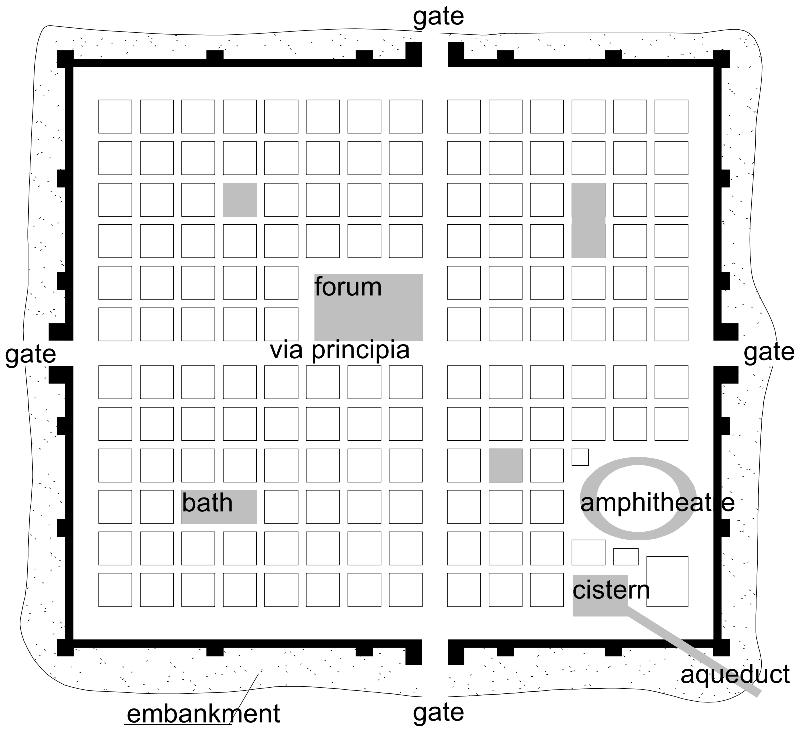
No society wielded the tools of geometry earlier and more thoroughly in the process of establishing sovereignty than did the Romans. For the Caesars the process began during the course of conquest itself. The geometry of the Roman *agrimensor* (land measurer) was that of angled, straight and parallel lines, the same geometry covered in the previous chapter. Straightforward and relatively basic, it was nonetheless one of the Romans most powerful tools of conquest.

In 1785 the fledgling United States began a program of organizing its western lands – then the current Midwest – into a systemic division of a plotted grid. Even before the drafting of a constitution surveyors began to draw this grid over the land.

Every 5 mile x 5 mile unit was known as a township and each square mile was a section. Townships were enumerated according to coordinate axes called meridians, which ran north and south, and range lines, which ran east and west. Such a survey, referred to as a cadastral survey, permitted the efficient recording of land ownership.

Left: The flatter the land the greater was the mark of the grid. This false color satellite photograph of western Kansas farmlands clearly derives its pattern from this grid. The circular shapes are the result of rotating irrigation sprinklers.

Right: Roman city planning also exploited the grid, as this typical town center demonstrates. Note the fortifications remaining from when the colony was a fort.



The Romans conquered by marching in and immediately setting up a colony, (or *colonia* in the original Latin). The first step was to establish an encampment for the incoming legion of 5000-6000 soldiers. The army meant for the encampment, or *castrum*, to become permanent, and so it was laid out with an eye to eventually establishing it as a town – a town for which the rank and file soldiers were to become the main citizens.

The layout centered around two crossroads, or *via principia*. Set at right angles, these future main streets connected with four gates set in a rectangular embattlement that surrounded the camp. At this central locale the legion's commanding officers (*praetoria*) bivouacked. The rest of the territory within the walls divided into grids, in which were built barracks for the *centuria*, fighting companies of 100 men each.

As the camp evolved into a town this center developed into a planned trading and meeting center called a forum. Other blocks were set aside for other civic functions including entertainment. One block on the edge of town became the location of an amphitheater.

centuriation

The real genius of Roman conquest resided in the pension system set up for the *centuriae*. Upon completion of their service each soldier received a sum of money and a plot of land outside of the encampment. For financially afflicted Romans the army thus offered a means to rise from their poverty and to become land owners and thus full-fledged citizens of the republic. For the empire this ensured that each fortified camp was surrounded by a settlement of thousands of citizens who were also a trained reserve of soldiers ready to fight at a moment's notice.

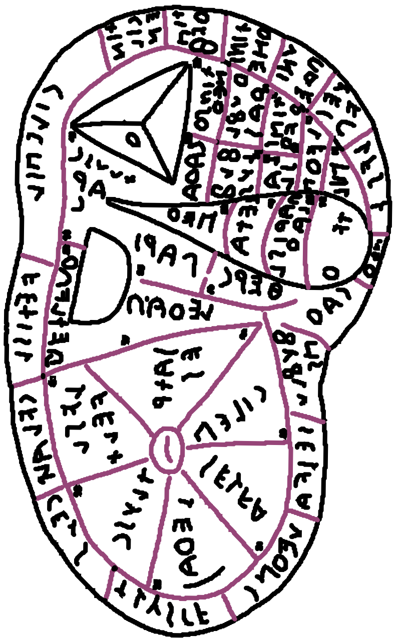
The origins of the grid in city planning date back to Neolithic towns, especially those on the flat plains of Persia, which today span Iran and Iraq. Whenever possible the Romans also adhered to the orderliness of the grid, but beyond the town walls they valued practical use of the land even more. They set such factors as drainage and wind protection before an arbitrarily ordered grid. Consequently their cadastral surveys of the hilly lands of the Mediterranean Basin created patterns that mixed the natural lay of the land with centuriated patches of order.

Below: This satellite photograph of western Turkey conveys the effect of centuriation imposed upon this varied landscape.

As the fortified camp morphed into a town, the surrounding area was surveyed into a cadastre, a systematic division of the land in which the soldiers' plots were assigned and recorded. During the conquest of the Italian peninsula *mensores* divided the cadastre into units of about 125 acres, or (50 hectares) that each comprised 100 lots, one for each soldier in a *centuria*. This same term then applied to that unit of land and stood as the standard unit of land parceling throughout the run of the empire. Centuriation is the current term for the process of surveying the grid of *centuria* and by extension the surveying of ancient Roman grid plots in general.

While large by comparison to a town lot of today, this was insufficient to farm for a living. The benefit to the town, however, was that the soldiers became businessmen and tradesmenresulting in the strong middle class essential to the economy of a town.

When the Roman Empire extended into the rest of Europe and across the Mediterranean, it upped the land allotment to colonists by thirty-fold, permitting the lucky landholder to make a substantial living on the land itself. The Caesars used such generous land grants to plant cadres of loyalists in the far reaches of the empire.



<u>Diagram from the Piacenza liver</u>.

The Romans borrowed their augury techniques from the Etruscans, who had pre-dated them on the Italian penninsula. The Piacenza liver is a bronze Etruscan sculpture of a sheep liver inscribed with a chart denoting significant divisions of the liver and their correspondent meaning. Named for the Italian town where it was found, its main purpose was most likely instructional..

Hepatoscopy, as the reading of animal livers is known, was the most popular method of augury used by Roman priests in determining fortune. The division of the liver into various geometric regions reflected divisions of ritual spaces and astronomical geometry, too.

The Roman town divination ritual was called an auspicia and it is the root of the English word auspicious. The area, position and direction of the town as determined by the auspicia are called the town's auspices.

Tools of the Trade

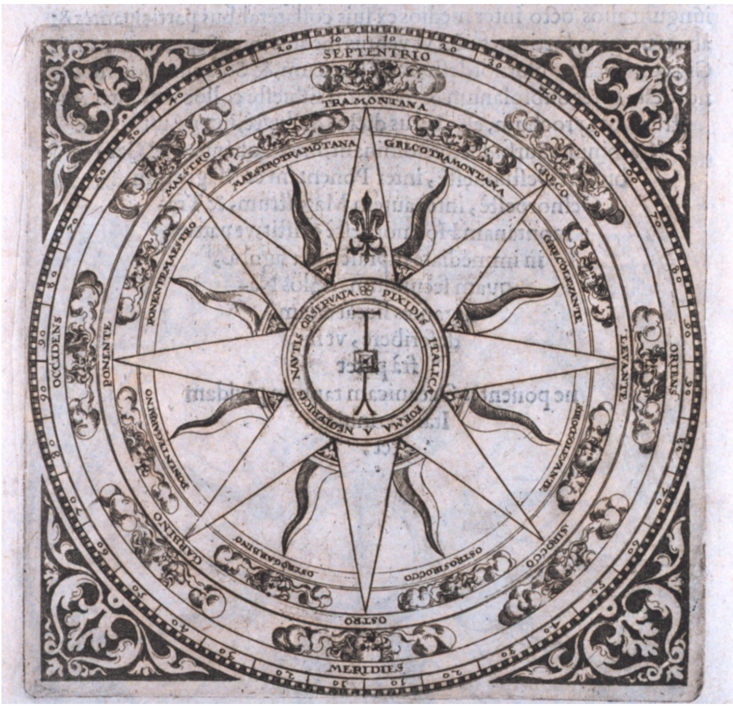
In drawing up plans and maps and in solving problems in the field the compass and straight edge were brought to bear, but in marking the land itself the *agrimensores* applied their own specialized tools. Among these were augury, the *amusium*, the gnomon, the level, the plumb bob, the *groma* and the *dioptra*.

The geometry remained the same as on paper. The knowledge of this geometry and the skill in applying it to the land were the *agrimensores* stock in trade.

augury

This was the job of a priest, not a surveyor! Though practical reasons -- the banks of a river, the lay of the land, for example -- held greatest sway, all things being equal priests were called in to help determine the most propitious location and orientation of the building site.

Animals of the region, such as a pheasant or a rabbit, came under the priest's knife to have their livers read for propitious or ominous signs. Several animals may have given their lives and several priests may have been consulted in order to make their learned sacred determinations.



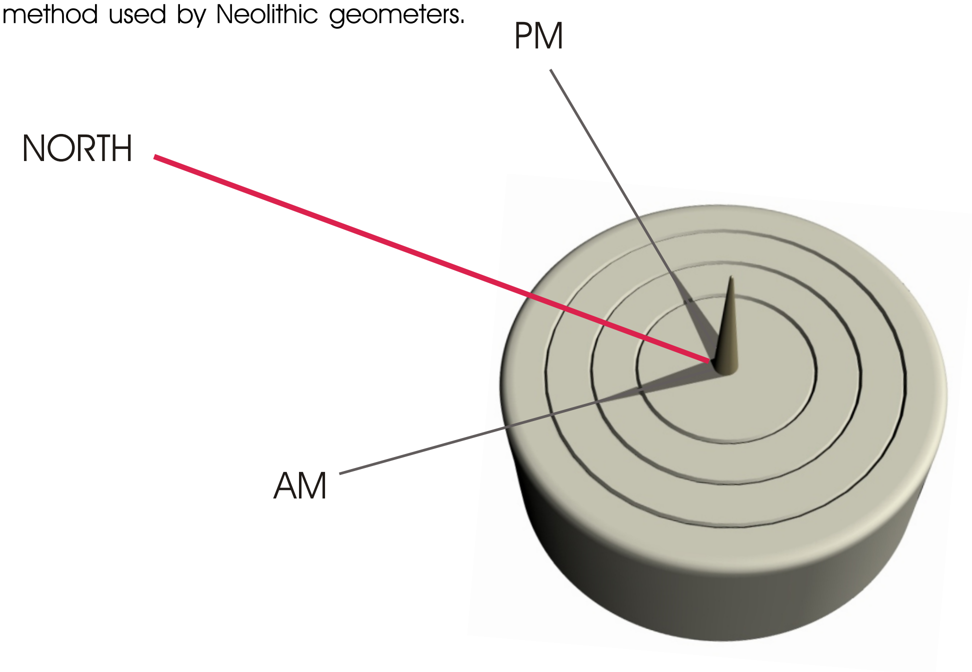
A decorative wind rose in: Philosophi ac medici.... by Fabrizio Padovani, 1601. P. 28. libr0009, Treasures of the NOAA Library Collection; Archival Photograph by Mr. Sean Linehan, NOS, NGS

The orienting of new colonia considered land and water access, propitious augury and prevailing winds. The alignment of the town would factor in the wind and weather conditions at its particular site. It would be a mistake to found a town on the wind-ward side of a hill, or to align streets to enable bitter winter winds to course through the town.

The wind rose was a chart recording local wind conditions by denoting the frequency, strength and directions of winds throughout the year. Like most Mediteranean seafaring peoples, the ancient Romans had dozens of names for winds according to their direction, strength, season of occurrence and dampness. Some of these names still appear on this 17th century rose.

the amusium and gnomon

The *mensores* measured the orientation of the *via principia* and the future colony as a whole in reference to true north. To do so tThe *mensores* used an *amusium,* a round level stone inscribed with a series of concentric circles. The gnomon, a metal pointer, stood upright at the circles' center. The method used by the mensores was a refinement of the method used by Neolithic geometers. (See page 7)

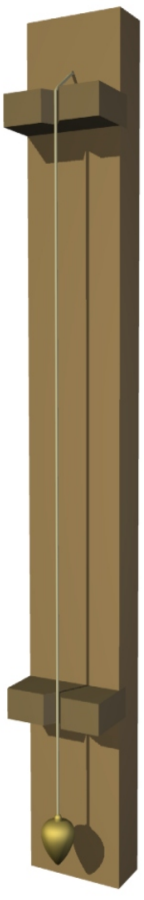


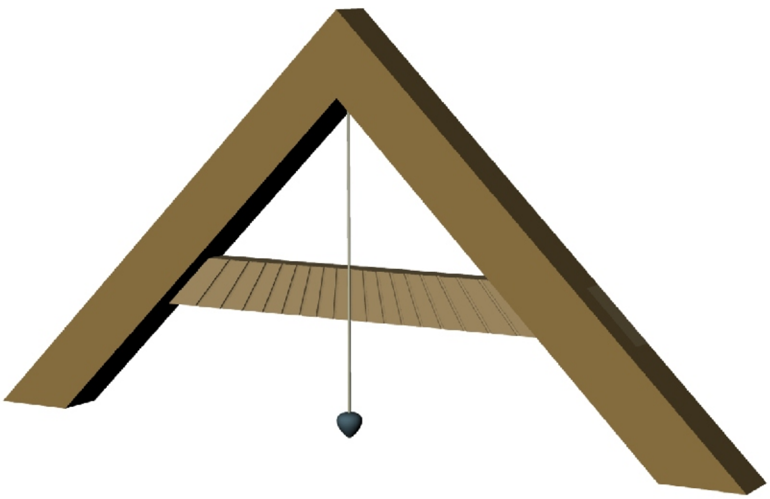
As the gnomon's shadow moved across the top of the *amusium*, the *mensor* would mark the point at which the tip of the shadow touched one of the concentric circles in the morning and that same circle again in the afternoon. By bisecting the angle these two points formed with the base of the gnomon the *mensor* could determine north within one degree of precision.

the level and plumb bob

The Romans used two types of levels: the water level and the inclinometer. The water level used the fact that water always seeks the same level, i.e., the surface of a basin of water always remains level. The Roman water level was in effect an elongated basin with lines incised at each end, both equidistant above the bottom of the basin.

The inclinometer featured a braced triangle with a plumb bob hung from is apex. The plumb bob itself was simply a weight attached to a string that the pull of gravity tugged into a perfect vertical line. With the point marked at which the plumb met the base of the triangle at right angles, a *mensor* could easily read level. Other markings calibrated the angles of incline, as well. Between the two levels the water level measured most accurately and was the instrument of choice in constructing the famed aqueducts.





The earliest uses of the plumbed line was to establish a perfect vertical and to accurately sight along a straight line. Using this vertical as a reference, tools like the inclinometer above could give a quick readout on the vertical slope of a line. The vertical level to the left, was originally developed by the Egyptians to aide in aligning posts and columns in both side-to-side and front-to-back directions simultaneously.

The* groma *(following page) exploited the sighting function of two plumbs to rapidly layout right angled boundaries of land parcels.

decempeda

The *decempeda* (Latin for "ten feet") was the *mensores* standard measuring rod. A straight wooden staff with copper or bronze end caps, it was ten Roman feet, or about 9.6 modern feet, in length and was the major tool for distance measuring. For finer measures the *mensores* carried a small folding ruler.

the groma

Teams of *mensores* arrived at the chosen encampment site well ahead of the marching soldiers, and unpacked their tools. First out of the sack was the *groma,* a sighting tool whose function was to demarcate the basic grid on which the camp was organized.

The *groma (opposite page)* was unique to the Romans and consisted of several parts that could be quickly assembled: a shaft, which, into one end, the *menso*r fitted a large metal point for securing it in the earth; and, in the other end, a rotating metal arm that cantilevered out from the shaft. Mounted on the end of the arm like a horizontal wheel were wooden cross arms that could be rotated to line up in any set of four perpendicular directions. Hanging from its center was a pointed plumb bob.

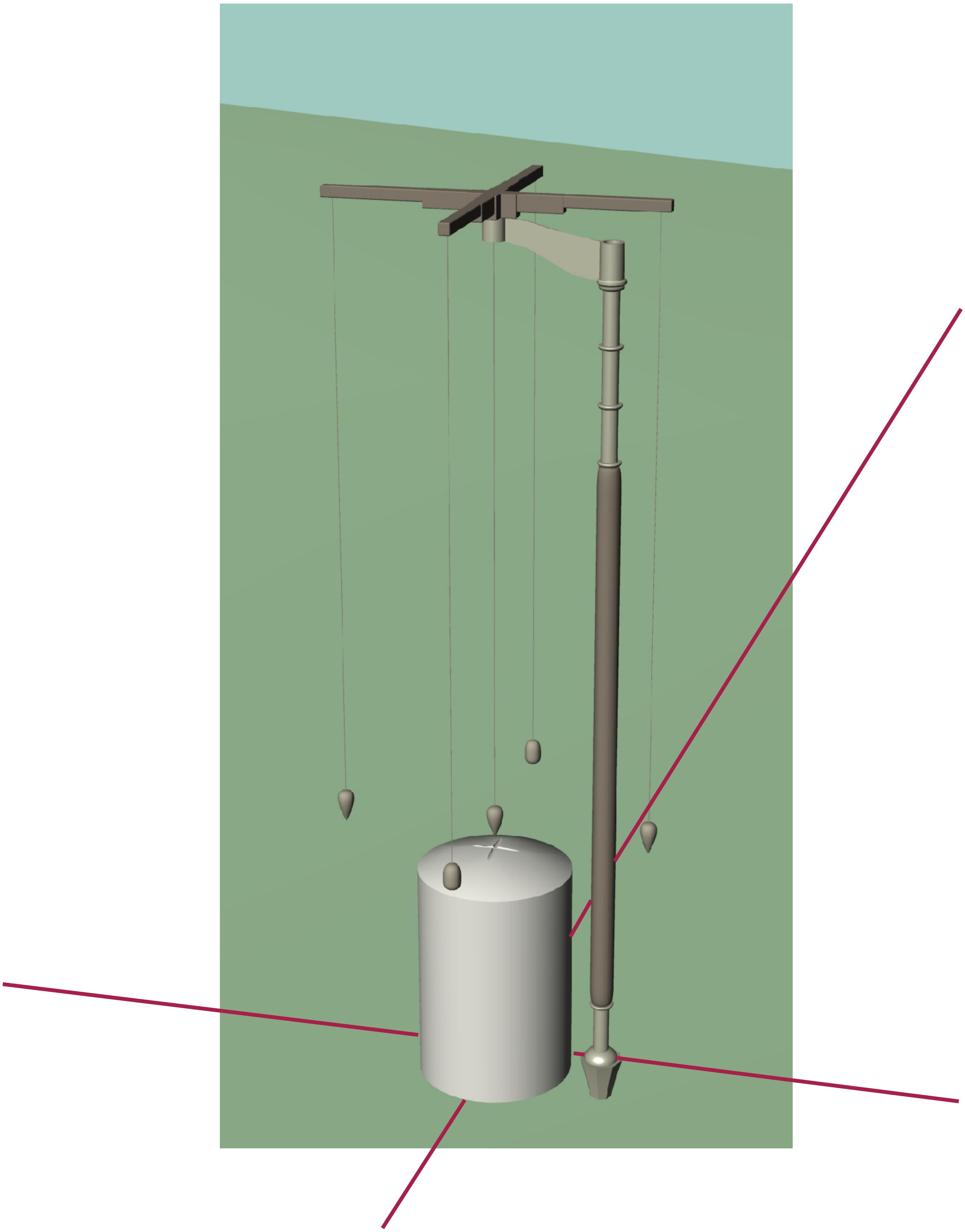
Mensores used the plumb bob to center their groma over an *amusium* or over a *cippus (opposite page),* a pedestal used by the Romans to mark key points in demarcating the land. At the ends of the cross arms were attached four more suspended weights. Using the taut strings to sight across both diagonals the team could quickly layout the organizational grid.

the dioptra

By far the most used tool, the *groma* quickly and efficiently layed out horizontal right angles. Where more complex angles or vertical angle measures were necessary, such as in hilly terrain or for engineering fortifications, the *mensores* turned to the *dioptra*.

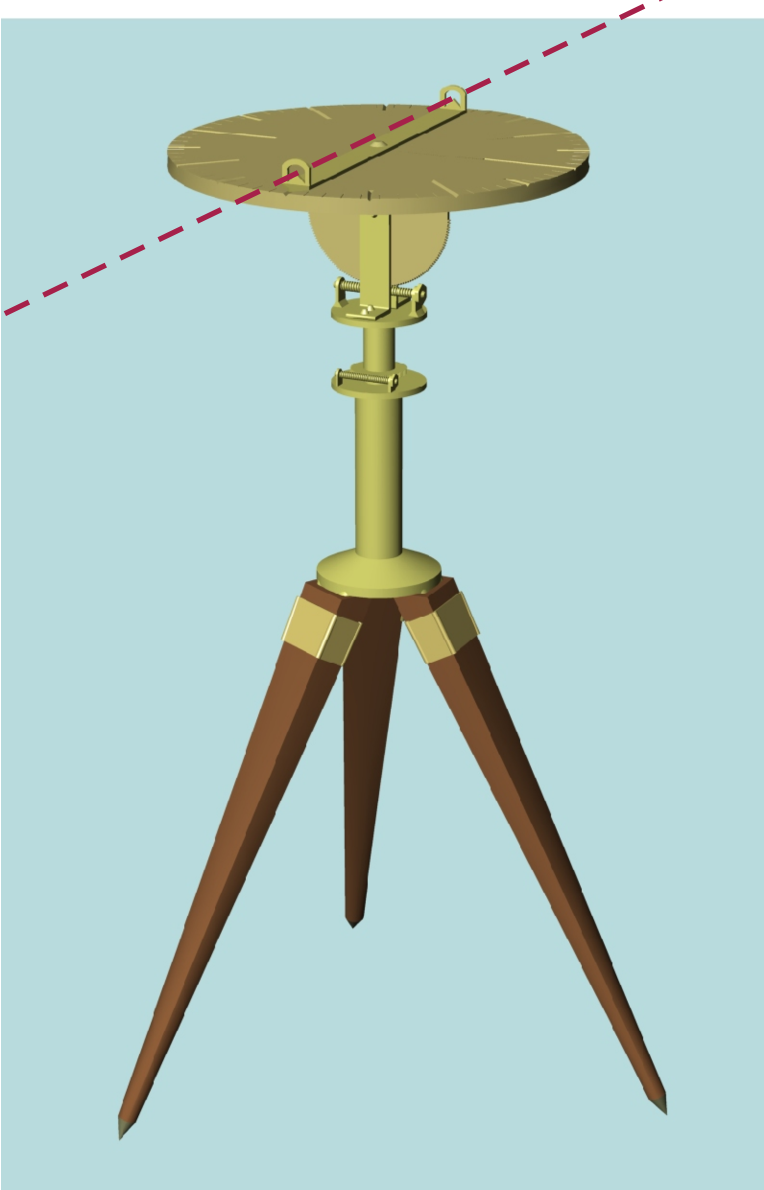
This was an all purpose instrument and the forerunner to modern surveying instruments and the primary surveying tool of the Roman engineer. It could be used to measure all horizontal and vertical angles and could also serve for leveling. Variations of the *dioptra*'s design remained in use throughout the Middle Ages and well into the Renaissance.

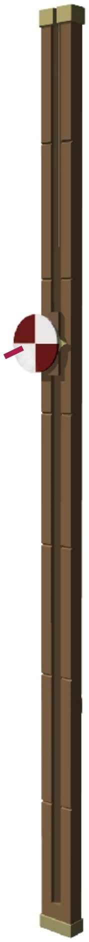
The* decempedia *(right) was most accurate for shorter distances. This tool capitalized on the fact that wood is resistant to expansion and contraction along the length of its grain and the metal tips could be trimmed for accuracy. For long distances equivalent to miles and kilometers the Romans used a cart called an* odometer *that recorded the turns of its wheels to provide distance.



For ***horizontal measure*** the *dioptra* featured a circular table affixed to a tripod and calibrated with angles like a protractor. Its user could level the table by adjusting the tripod and then fine tuning with four screws and two water-filled levels set 90° to one another. Once leveled the *dioptra* was ready for measuring the angle between two distant objects. For this purpose a rotating bar with sights aligned on each end swiveled at the center of the table.

This sight was first set to zero and the *agrimensor* turned the table, which also rotated, until the sight lined up on the first object. Locking the table in place he then rotated the sight until it aligned





This reconstruction of a dioptra *illustrates a description published in the first century by the Greek mechanical engineer, Heron, in his book* Dioptra. *Evidence for its origins dates back to the 3rd century BCE, when Greek astronomers began using a similar instrument to determine the position of stars. Ancient* mensors *regarded the* dioptra *to be a precision instrument and, thus not typically used by the ordinary* agrimensor. *Rather it played a crucial role in more sophisticated engineering, such as the famed aqueducts of Rome.*

The dioptra remained in use until the 17th century when Leonard Digges replaced its sighting bar with telescopic sights, and invented the theodolite of modern surveying. (Following page.)

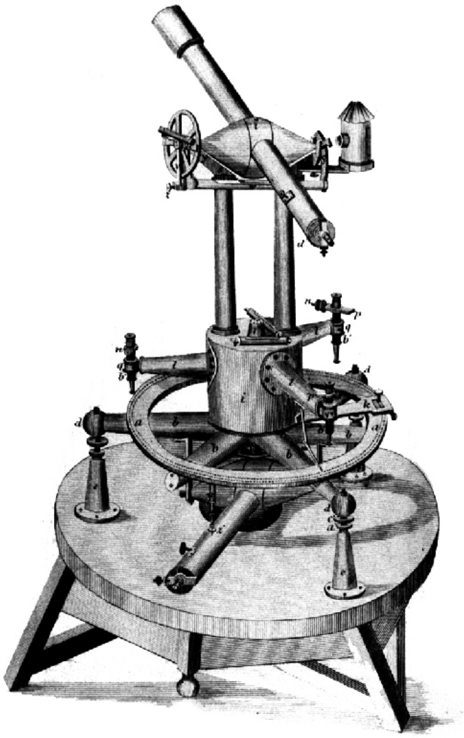
To the second object. The *mensor* could then jot down the angular reading directly from the table.

Albeit indirectly, the *dioptra* could also measure horizontal distances, especially those difficult or impossible to reach with rods or ropes. To measure the width of a raging river, for example, the *agrimensor* would choose a rock or other marker across the river and select two points of known distance on his bank of the river. These points demarcate two vertices of a triangle with the line between them forming the base. Setting up on each point and measuring the angle between the other point and the rock across the river will give a known triangle whose altitude is the distance across the river.

The *dioptra* was flexible enough to execute ***vertical measure***, too. From the level position the *mensor* could employ the *dioptra* to read changes in elevation. Typically the *amusium* would serve as a benchmark, that is, as a fixed reference from which the vertical height of any point on the site could be measured as a plus or minus value. An assistant held a calibrated rod on the *amusium* while the *mensor* peered through the *dioptra's* sights and read the value where the crosshairs hit the rod. In contemporary surveying this reading is termed the instrument height.

As the assistant moved to the rod to key points throughout the site the *mensor* would take similar readings. The differences between the instrument height and these readings yielded the elevation of each point relative to the zero point at the benchmark. This data provided the means to figure the varying slopes of the site.

In order to measure vertical angles the *dioptra's* table was mounted on a vertical semi-circular disk also calibrated with angle markings. Turning a screw whose threads engaged the metal disk's toothed edge would cause the table to tilt and allow the sighting of up and down angles.



Troughton 24-inch theodolite drawn by Caroline Hassler; from "Papers on various subjects connected with the survey of the coast of the United States", by Ferdinand Hassler; March 3, 1820.

Image ID: libr0059, Treasures of the NOAA Library Collection

Archival Photograph by Mr. Sean Linehan

Geometry and design, like any other areas of knowledge, do not exist in a vacuum. From a purely theoretical point of view it is possible and extremely useful to treat both areas as purely abstract and self-contained realms of relationships. However, as human artifacts they participate in cultural and social realms. As such they develop applications and meanings that affect human affairs on a variety of levels.

Among the many aspects of Greek and Roman culture that still affect human affairs is the use of geometry in the design of lands, economies and societies. Though at the expense of the peoples they subjugated, the Romans used the surveyors' geometry to create an empire wide citizen class that continues as a model for republican democracies.