Ancient Engineers' Inventions

HISTORY OF MECHANISM AND MACHINE SCIENCE

Volume 8

Series Editor

MARCO CECCARELLI

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Ancient Engineers' Inventions

Precursors of the Present

Springer

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Preface

We live in an age in which one can easily think that our generation has invented and discovered almost everything; but the truth is quite the opposite. Progress cannot be considered as sudden unexpected spurts of individual brains: such a genius, the inventor of everything, has never existed in the history of humanity. What did exist was a limitless procession of experiments made by men who did not waver when faced with defeat, but were inspired by the rare successes that have led to our modern comfortable reality. And that continue to do so with the same enthusiasm.

The study of the History of Engineering is valuable for many reasons, not the least of which is the fact that it can help us to understand the genius of the scientists, engineers and craftsmen who existed centuries and millenniums before us; who solved problems using the devices of their era, making machinery and equipment whose concept is of such a surprising modernity that we must rethink our image of the past.

But there is an even more important reason to study the History of Engineering: the authors believe that it is impossible to have a true technical culture if the ideas and the work of those who came before us are ignored. Culture, in whatever field, consists in understanding and not simply in know-how. For this reason it is essential to learn how a certain phenomenon was understood and how the application of that knowledge evolved through the centuries. For the same reason it is important that the scientists of our generation transmit an interest in and taste for the accomplishments of ancient engineers. Young engineers should be familiar with the knowledge of the past if they are to understand the present and perceive the future. Moreover, engineering must be considered that discipline that tries to give to man the possibility to outperform his body's limits.

This book describes the inventions and designs of ancient engineers that are the precursors of the present. The period ranges mainly from 300 B.C. to A.D. 1600 with some exceptions belonging to ages before and after these years.

As for the very ancient inventions, in the book there are descriptions of inventions (documented by archaeological finds mainly from Pompei, Hercolaneum and Stabia) of which often very little is known.

Some of the inventions are in the military field since (unfortunately) many inventions and technological innovations were conceived starting from military applications.

In this volume the authors have considered several important fields of engineering; in each of these fields, they highlight the first examples of the inventions (and constructions) accomplished by scientists and engineers.

Although many of these inventions are extremely old, the ones presented in this book are precursors of the knowledge and inventions of our era. In addition, many of them reveal a surprising modernity in their conception, in their scientific and technical design and even in their shape and function.

The book is divided into six parts.

The first four parts pertain to specific fields and present inventions conceived up to the late Roman Empire. These are inventions that are representative of the engineering genius of the ancients and that may be considered as milestones, each in their respective field.

The fifth part also refers to separate fields of engineering innovations (such as textiles and automation), but concentrates on more recent centuries.

The last part, consisting of Chapter 16, deals with building construction techniques and not devices. These building techniques, in the authors' opinion, can also represent inventions.

For each of the inventions presented, even the ancient ones of many centuries past, the authors provide three elements of research and reference:

Written documents (the classics)
Iconic references (coins, bas-reliefs, etc.)
Archaeological findings

The only exception is when an exhaustive and detailed treatise by the inventor himself is available (e.g.,Vitruvius).

Many devices and building constructions described in the book pertain to the age of the Roman Empire; it could be presumed that this is so because the authors are Italians, but this is not the reason. Undoubtedly the Roman Empire was a society of great accomplishments (probably even today not yet completely understood) in many fields of science, technology and law; they started from the Italian peninsula but they do not belong just to the Italians. First of all, most of the inventions and the technology of the Roman Empire were not invented by Latin inventors; in fact, one of the merits of the Romans consisted in recognizing, appreciating and using the intellectual abilities of other peoples. In addition, the quality of organization and the "sense of a State" has been retained more by the German and Anglo-Saxon peoples than by the Latin ones; hence the heritage of the Roman Empire, today, belongs to people who study and appreciate those ages and those men. Moreover, living in Italy, the authors have had more chance to see and investigate Roman relics. However, certainly a large number of the inventions that are precursors of the present were developed at that age.

As a point of reference, the authors think that the first industrial revolution started during the Roman Empire. Many aspects suggest this hypothesis: the Romans had a strong incentive to make great progress towards unification and standardization in the production of goods. At certain periods, the Roman Armed Forces had up to 500,000 men, all of whom had to be equipped with everything they needed to live, clothe and shelter themselves and fight. The army needed unified and interchangeable equipment because its military units had to be able to go anywhere in various sized units; this meant that unified industrial production systems were crucial to fulfil the army's needs.

The resulting standardization, that probably was devised for those military uses, was subsequently extended to civil applications: many of the components used in the various systems, such as hydraulic valves and pipes (see Chapter 8), cart wheels and gauges (see Chapter 10) and so on, had standardized dimensions and were interchangeable throughout the Empire. This history was clearly delineated by Vitruvius, the most famous Roman engineer.

Finally, the authors did not write this book for engineers only; hence they describe the devices in details that do not assume wide technical knowledge. The authors' main aim is to try to communicate their enthusiasm for the inventions and the inventors of the past and, possibly, to make their contribution to the fascinating study of the History of Engineering.

Napoli, X 2008

Part I – MEASURING THE ENVIRONMENT

Introduction

The first part of this book is divided into four chapters and mainly pertains to measurements. In the first three chapters, measures and measurement devices are presented; in the fourth are reported the first computing devices that were developed before the invention of computing machines.

The first step towards the establishment of scientific standards was to build a foundation for measuring of the environment. Toward this end, the first step was to define a system of units; the demand for such a system was certainly generated by people in the trades, but units of measure were obviously perceived as indispensable for any scientist, inventor or engineer to study a chosen science and to describe designs of experiments and constructions.

To the best of our knowledge, the first measure unit systems were probably established in the East in Mesopotamia, Persia and India, then in Egypt and Greece and later in Rome.

Most of the oldest inventions reported in this book were made by Greek–Roman inventors who, in their original writings, described their devices using Greek or Roman units; furthermore, at that time, the latter of these units were used all over the Roman Empire. For this reason the authors considered it useful to report both these systems of units in the tables that follow.

Ancient Greek units

Length units

In Tables I.1 and I.2, the ancient Greek length units are reported. For small lengths the unit was the dactylos (pl. dactyloi) meaning finger; for longer lengths the unit was the pous (pl. podes) meaning foot.

Table I.1 Greek length units.

Greek name	Latin alphabet	English name	Value (dactyloi)	S.I. equivalence
δάκτυλος	dàctylos	Finger	1	≈19.3 mm
κόνδυλος	còndylos	Middle joint of finger	2	
παλαιστή, δῶρον	Palaiste or doron	Palm	4	
διχάς, ἡμιπόδιον	Dichas or hemipodion	Half foot	8	
λιχάς	lichàs	Span of thumb	10	
ὀρθόδωρον	orthòdoron		11	
σπιθαμή	spithamè	Span of all fingers	12	
ποῦς	pous	Foot	16	≈308.3 mm Attic ≈ 296 mm
πυγμή	pygmè	Elbow to base of fingers	18	
πυγών	pygòn		20	
πῆχυς	pèchys	Cubit	24	
πῆχυς βασιλήιος	pèchys basilèios	Royal cubit	27	

Table I.2 Greek length units.

Greek name	Latin alphabet	English name	Value (ft)	S.I. equivalence
ποῦς	pus	Foot	1	≈308.3 mm Attic ≈ 296 mm
ἁπλοῦν βῆμα	aploun bema	Single pace	2.5	≈0.75 m
διπλοῦν βῆμα	diploun bema	Double pace	5	≈1.5 m
ὀργυιά	orguià	F or stretch of both arms	6	≈1.8 m
ἄκαινα	àkaina		10	≈3 m
πλέθρον	plèthron	Breadth of Greek acre	100	≈30 m
στάδιον	Stàdion	Stadium	600	Attic ≈ 177.6 m Olympic ≈ 192.27 Walking ≈ 157.5m
δίαυλος	Diàulos		2 stadia	≈355.2 m
ἱππικόν	hippikòn		4 stadia	≈710.4 m
δόλιχος	dòlichos		12 stadia	≈2.131 km
παρασάγγες	parasànghes		30 stadia	
σχοινός	schoinòs		40 stadia	

Area units

The main unit of surface was the square plethron; traditionally it was the amount of land a yoke of oxen could plough in 1 day and, more specifically, it was any area equal to the area of a square whose sides are 100 podes (1 plethron) in length; submultiples were the aroura (1/4 of plethron) and the sixth (1/6 of plethron).

Volume units

In Tables I.3 and I.4, the ancient Greek volume units are reported, for liquid and solid respectively.

Table I.3 Greek volume units, liquid.

Greek name	Latin alphabet	English name	Value (cotylai)	S.I. equivalence $m^3 \times 10^{-3}$ (=litre)
κύαθος	kýathos		1/6	≈0.046
οξυναφον	oxynafon		1/4	
ημίκοτύλη	emìkotýle		1/2	
κοτύλη	cotýla	Cup	1	≈0.275
ημίχους	emìchous	Half jug	6	
χοῦς	choùs	Jug	12	≈3.3
μετρητής	metretès		144 ≈1 amphora wine	≈39.4

Table I.4 Greek volume units, solid.

Greek name	Latin alphabet	English name	Value (cotylai)	S.I. equivalence $m^3 \times 10^{-3}$ (=litre)
κοτύλη	cotýla	Cup	1	≈0.275
χοῖνιξ	choìnix		4	
ἑκτεύς	hecteùs		8	
μέδιμνος	mèdimnos		6	

Weight/mass units

In Table I.5 the ancient Greek weight/mass units are reported. It has to be pointed out that in ancient times (and until just a few centuries ago), conceptually the differences between force (weight) and mass units was not very well defined. For this reason, in the fourth column of the following table, the S.I. equivalents are given for the masses; obviously, the S.I. equivalents for the forces are obtained in Newtons by multiplying the masses by 9.81.

Table I.5 Greek weight/mass units, solid.

Greek name	Latin alphabet	English name	Value (obola)	S.I. equivalence (g) Attic/Euboic	S.I. equivalence (g) Aeginetic
ὀβολός	obolòs	Obol		0.72	1.05
δραχμή	drachmè	Drachma	6	4.31	6.3
μνα	mna	Mina	600	431	630
τάλαντον	tàlanton	Talent	60 mina	25.86 kg	37.8 kg

Roman units

Length units

In Table I.6 the roman length units are reported.

Table I.6 Roman length units.

Latin name	English name	Value (ft)	S.I. equivalence
digitus	Digit	1⁄16	18.5 mm
uncia	Inch	1⁄12	24.6 mm
palmus	Palm	1⁄4	74 mm
pes	Foot	1	296 mm
cubitus	Cubit	1 + 1⁄2	444 mm
gradus	Step	2 + 1⁄2	0.74 m
passus	Pace	5	1.48 m
pertica	Perch	10	2.96 m
actus	Arpent	120	35.5 m
stadium	Stadium	625	185 m
milliarium	Mile	5,000 ft = 1,000 pace	1.48 km
leuga	league	7,500	2.22 km

Area units

In Table I.7 the roman area units are reported.

Table I.7 Roman area units.

Latin name	English name	Value (acres)	S.I. Equivalence
pes quadratus	Square foot	1/14,400	~876 cm²
scripulum	Square perch	1/144	~8.76 m²
actus minimus	Aune of furrows	1⁄30	~42 m²
slima	Rood	1⁄4	~315 m²
actus quadratus(acnua)	Acre	1	~1,260 m²
iugerum	Yoke	2	~2,520 m²
heredium	Morn	4	~5,040 m²
centurium	Centurie	400	~504,000 m²

Volume units

The roman volume units are reported in Tables I.8 (liquid) and I.9 (solid).

Table I.8 Roman volume units, liquid.

Latin name	English name	Value (sesters)	S.I. equivalence $m^3 \times 10^{-3}$ (=litre)
ligula	Spoonful	1⁄48	~0.01125
cyathus	Dose	1⁄12	~0.045
sextans	Sixth-sester	1⁄6	~0.09
triens	Third-sester	1⁄3	~0.18
hemina	Half-sester	1⁄2	~0.27
choenix	Double third-sester	2⁄3	~0.36
sextarius	Sester	1	~0.54
congius	Congius	6	~3.25
urna	Urn	24	~13
amphora	Jar	48	~26
culleus	Hose	960	~520

Table I.9 Roman volume units, solid.

Latin name	English name	Value (pecks)	S.I. equivalence $m^3 \times 10^{-3}$ (=litre)
acetabulum	Drawing-spoon	1⁄128	~0.0675
quartarius	Quarter-sester	1⁄64	~0.0135
hemina	Half-sester	1⁄32	~0.27
sextarius	Sester	1⁄16	~0.54
semodius	Gallon	1⁄2	~4.33
modius	Peck	1	~8.66
quadrantal	Bushel	3	~26

Weight/mass units

In Table I.10 the roman weight/mass units are reported; as for the S.I. equivalences, the same observations made about ancient Greek weight/ mass units must be made.

Table I.10 Roman weight/mass units.

Latin name	English name	Value (drachmae)	S.I. equivalence
chalcus	chalcus	1/48	~71 mg
siliqua	siliqua	1/18	~189.33 mg
obolus	obolus	1/6	~0.568 g
scrupulum	scruple	1/3	~1.136 g
drachma	drachm	1	~3.408 g
sicilicus	shekel	2	~6.816 g
uncia	ounce	8	~27.264 g
libra	pound	96	~327.168 g
mina	mine	128	~436.224 g

Chapter 1 – MEASURING MASS

Introduction

Measuring mass and force, together with the measuring of the linear dimensions that will be exposed in the next chapter, represent the first step in developing science and technology. Examples of balance scales from Mesopotamia and Egypt are dated to the 5th millennium B.C. but their use became common in nearly all populations of that time.

With respect to devices, the first ones were probably those designed to measure mass, since a yarn with some knots to measure a length can not be considered a real device. The impetus for the design of mass measuring devices quite certainly came from the trades.

It is interesting to consider that, according to the Egyptians, the balance scale was already considered a symbol of justice, even for the life after death. The god Anubis, in fact, was also the guardian of the scale balance that was used to measure the weight the soul; if the soul was not heavier than a feather, she was given to Osiris; otherwise it was eaten by Maat. Figure 1.1 is a picture of an Egyptian painting showing the god Anubis and a balance scale.

Fig. 1.1 Balance scale and god Anubis.

C. Rossi et al., *Ancient Engineers' Inventions: Precursors of the Present*,
History of Mechanism and Machine Science 8, 7–12.

Ancient balance scales were built in two shapes: one had two arms having equal length, the other had arms of different lengths; the first will be indicated simply as a "balance scale" while the second will be indicated as a "pendulum scale".

1.1 The balance scale

The word balance (which is similar in many languages) comes from the Latin "bi lanx", meaning double pan. The balance scale essentially consists of a couple of pans suspended from a yoke; the latter is suspended at the middle point between the points at which the dishes are suspended. The use is very easy and well-known: the object that is to be weighed is located on one pan while on the other pan are placed weights having known value, until the yoke is horizontal. When the yoke is balanced, since its arms have equal length, the weights (and the masses) on both the pans are equal, hence the object's mass is given by the sum of the known weights on the other pan. Such a type of balance scale is common all-over the world and has been used for thousands of years by a great number of civilizations. In Figure 1.2 are pictured a Roman balance scale now at the Museo Nazionale, Naples, Italy (on the left) and a detail of a Roman bas-relief showing a large balance scale.

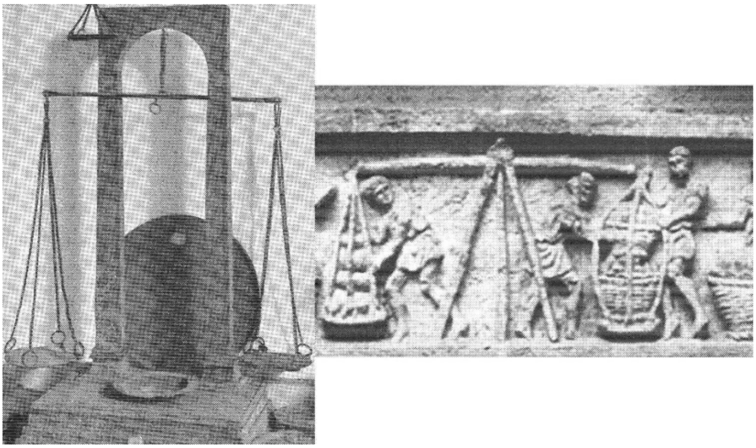

Fig. 1.2 Roman balance scales.

The mathematical theory of the balance scale is not very simple (and certainly was formulated thousands years after the first one had been built), but it is possible to briefly summarize the main aspects.

The precision of a balance scale depends on the quality of its components (mainly the yoke and the suspension pins) and the accuracy of the weights; the sensibility mainly depends on the yoke's weight and length hence on the balance size. For thousands of years balance scales have been built in a wide range of sizes, the big ones to measure the mass of large objects and the small ones to compare the weight (hence the value) of the coins.

1.2 The steelyard balance

The steelyard is also known as a Roman balance because it was invented by the Romans around the 4th century B.C. and was called "statera". In about the same period, about the 3rd century B.C., similar devices appeared in China. The working principle is shown in Figure 1.3.

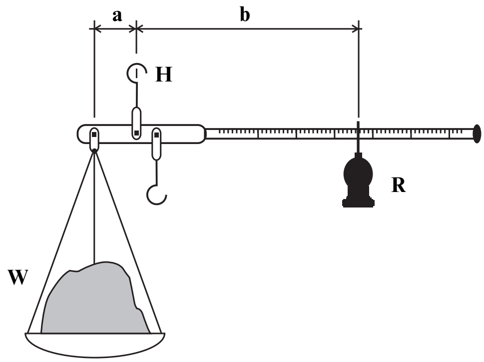

Fig. 1.3 Scheme of a steelyard balance.

The steelyard has two arms of different lengths; to the shorter one is linked a pan on which is located the unknown mass W, a known (and calibrated) counterweight R can slide on the longer arm that is graduated. When hung from the hook H, obviously the equilibrium is reached if both the momentums of W and R are equal with respect to the pivot of the suspension hook H:

$$W \cdot a = R \cdot b \;\Rightarrow\; W = a \cdot R/b. \tag{1.1}$$

Since the counterweight R and the arm's length a are constant, W is a function only of the distance b. To weigh an object it is only necessary to move the counterweight R along the arm till the steelyard is horizontal and then to read the weight on the graduation of the long arm. This device is generally less precise than the balance scale but it is very easy to handle and to carry since it does not require a set of known weights.

A very good description of the steelyard is given by Marcus Vitruvius Pollio (1st century B.C.), who was a Roman writer, architect and military engineer who will be widely mentioned in the following chapters of this book, in particular his famous treatise “De Achitectura”. It is interesting that Vitruvius, in his description, uses the term “momentum” with the same meaning of the English word in mechanics.

In Figure 1.4 is depicted an ancient steelyard found at Hercolaneum.

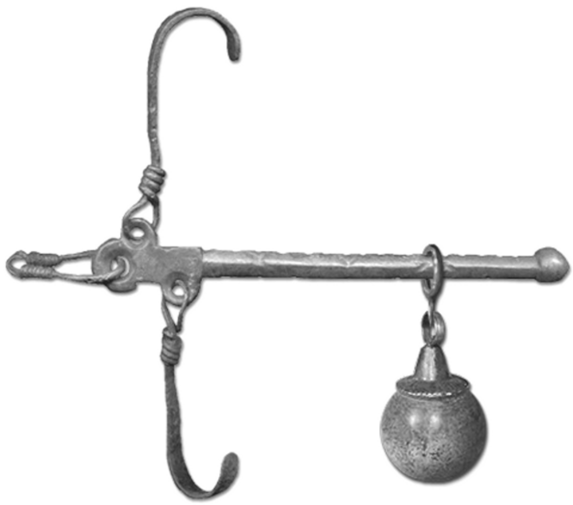

Fig. 1.4 Steelyard found at Hercolaneum.

A later description of the steelyard is given by Saint Isidore of Seville (Spanish name: San Isidro or San Isidoro de Sevilla, Latin name: Isidorus Hispalensis (~560–636 B.C.) who was Archbishop of Seville and one of the most educated men of that age; he wrote about liberal arts, law, medicine, natural science, and theology. In his treatise “De ponderibus et mensuris” (On the weights and measures), he calls the scale balance a statera while the steelyard is called “Campana” after the name of the Italian region Campania where, according to him, the first example of this device was found. Really the word “campana” does not appear in the classic Latin literature but only in later publications.

Observations

Balance scales having, substantially, the same shape as those built thousands of years ago, have been enhanced until the present day and were the only device to make accurate measures of weight till the very recent invention of electronic dynamometers. Some of those balance scales, built for laboratory use, have a sensibility of 0.1 mg in a range from 0 to 200 g.

Balance scales and steelyards were used to measure mass because the measurement is made by comparing the gravitational force acting on two masses; the authors think that ancient force measuring devices could have existed but they have not found any proof of this.

Also steelyards are still used; until a few years ago these devices appeared in most country markets. Some modern steelyards are still built in small sizes to weigh the gunpowder charge needed to load cartridges; these devices generally have a sensibility of 0.1 grain (=0.0065 g).

An interesting legend, told by Vitruvius, demonstrates that, in ancient times, the concepts of specific weight and density were well-known: when Hieron I became tyrant of Syracuse in Sicily (from 278 to 267 B.C.), he wanted to offer a votive crown made of solid gold to a temple; so, he gave the necessary amount of gold to a goldsmith. Once the crown was made, Hieron was suspicious that the goldsmith could have made the crown by substituting some of the gold with silver and so asked Archimedes, the well-known ancient scientist (Syracuse ~287–212 B.C.), to discover whether the crown had been made only with gold or not. Archimedes operated as follows:

1. He weighed the crown.
2. Then he got an equal mass of gold and an equal mass of silver.
3. Finally, he took a container full of water, put the gold mass in it and measured the water that spurted from the container that obviously represents the volume of that mass of gold.
4. The same was done with the silver mass and with the crown.

The volume of water that spurted from the container when the crown was immerged was lower than the water that spurted with the silver mass but more than the water that spurted with the gold mass; from this Archimedes concluded that the crown was not made of pure gold but of a gold with silver alloy.

Vitruvius does not tell us if Archimedes computed the gold amount that was substituted by silver but, on the basis of the described procedure, the computation is very easy:

$$\frac{Gold\ mass}{Silver\ mass} = \frac{Silver\ volume - Crown\ volume}{Crown\ volume - Gold\ volume}\ . \qquad (1.2)$$

This is a very simple equation that a mathematician such as Archimedes would probably have used. According to the procedure described by Vitruvius, Archimedes did not use any balance scale.

The same legend was told later but the procedure credited to Archimedes was different: on one of the pans of a balance scale was put the crown and on the other pan some gold having the same mass of the crown; in this way, the yoke of the balance was obviously horizontal. Then the balance scale was put into water: since the pan containing the pure gold went down, Archimedes concluded that the crown was not made of pure gold but contained silver.

The second procedure is more plausible because a certain amount of silver in the crown could have corresponded to a very little difference of volume that could have hardly been measured in that age. In any case, both procedures show that those concepts were known by scientists and engineers in those ages.

Chapter 2 – MEASURING DISTANCE

Introduction

As mentioned in the previous chapter, the measuring of distance (together with the measuring of mass and force) represent the first step in the development of science and technology. In addition, the first western scientists and engineers (e.g., Thaletes, Pythagoras, Archimedes etc.) were very deeply interested in the study of geometry.

It is also well known that in building temples and towns, accurate measuring of distances is essential. A powerful impulse in this field of knowledge was experienced during the Roman Empire.

As everybody knows, the Roman Empire was one of the most widely distributed powers ever to exist in human history. On the other hand, most people believe that technology and science were quite primitive during that era, and the study of them mostly neglected. Our study of the History of Engineering, however, has been of great help in recognizing that, contrary to science in general, mechanical knowledge was rather advanced, and we have been able to discover the function and the meaning of many archaeological finds and to analyze their ways of working. In particular, through the common efforts of archaeologists and engineers it was possible to demonstrate that many devices of present day common use were actually invented and built about 20 centuries ago.

In such a far-flung empire as that of the Roman, measurements of distances, both on land and at sea, played a crucially important role in governance and trade. One of the most important constructions the Romans built in Europe was, in fact, a widely dispersed system of roads. Most of those roadbeds are still in use today. In addition, since the sextant and the marine chronograph had not yet been invented, the only way to determine a distance on the sea was to measure the length of a ship's run.

C. Rossi et al., *Ancient Engineers' Inventions: Precursors of the Present*,
History of Mechanism and Machine Science 8, 13–25.

2.1 Jacob's staff, Astrolabe

When it was not possible to measure distances directly, because there was a deep gorge, wide river or sea inlet, a rudimentary range finder was used: Jacob's staff, also called baculum or cross-staff or radius. The precision of the instrument depended a great deal on the skill of the user, which was still rudimentary. Historically, the baculum was first used by the Egyptians, then the Jews and later the Arabs. It reached Europe during the Middle Ages, perhaps brought by the mathematician Levi ben Gerson (1288–1344). The oldest model consisted of a simple graduated rod along which slid a smaller cross-shaped one: the estimate was based on the similarity of right-angled triangles. The primitive nature of the instrument made it very approximate, even though its principle lies at the basis of modern optical telemeters. According to some scholars, the baculum was the precursor of the Latin radius, a completion of the Greek radius, also called Jacob's staff.

In Figure 2.1 a schematic reconstruction of a roman era staff or baculum is shown, with a medieval print illustrating the use of a staff or baculum.

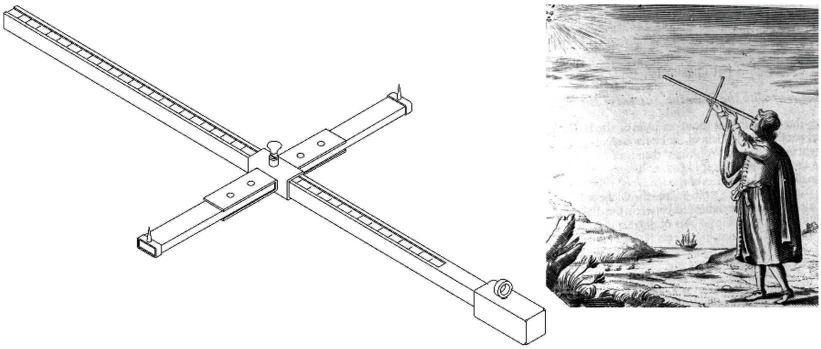

Fig. 2.1 Jacob's staff.

2.2 Range finders

In this section we discuss those ancient devices which made possible the development of topography.

2.2.1 Groma

It would be difficult to determine when the groma, a land surveyor's instrument was first invented: it may have originated in Mesopotamia, where it may have been taken from the Greeks around the 4th century B.C., and renamed gnomona or little star. The Etruscans then brought it to Rome, calling it cranema or ferramentum. It consisted of an iron or bronze cross from whose arms descended four plumb lines. Looking through the opposing pairs, the surveyor could identify two perpendicular directions, which allowed him to subdivide the land into orthogonal alignments.

In spite of the fact that this instrument goes back to very ancient times, it was in common use even centuries later. Proof is found in the remains of a groma discovered in Pompeii and its illustration on several funerary steles. As far as we can tell, the approximately 2 m long rod supported the cross well above the eye level of the user, who could therefore look freely through the plumb lines. The real limitation of the instrument was revealed when there was even a weak wind, as this caused the lines to oscillate and prevented a correct line of sight.

Figure 2.2 shows a virtual reconstruction of a groma and a bas-relief from the Roman imperial era representing a groma.

Fig. 2.2 Groma.

2.2.2 Surveyor's cross

This little deficiency of the groma was overcome with the surveyor's cross, either the drum or case version. In Figure 2.3 is shown a find and an authors' virtual reconstruction of this device.

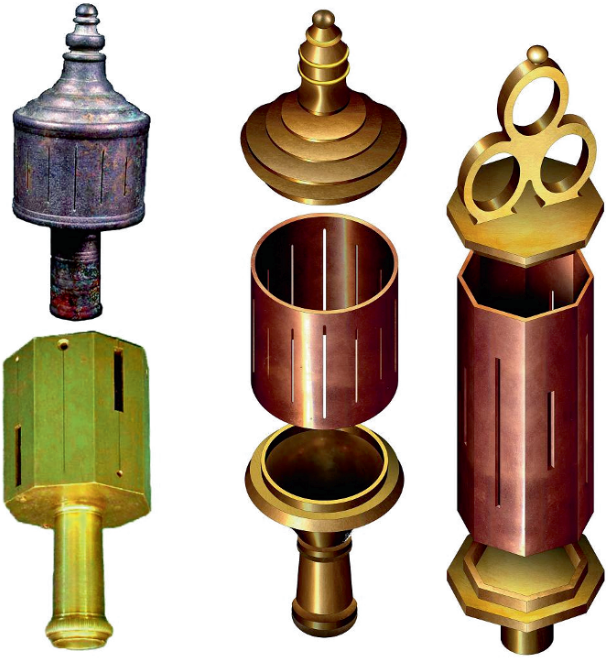

Fig. 2.3 Surveyor's cross: find and virtual reconstruction.

The function of the lines was carried out by thin slits, made at regular intervals, along the side of a cylindrical drum. In most models, these were placed at 90° intervals, decreasing to 45° in the more accurate ones. For more important uses requiring more than simple squaring, the distance was further decreased as low as 22°30′. By looking through the slit to its corresponding opposite, the surveyor could determine the correct direction; by holding the instrument stable, again looking through the slit at 90°, he could identify the direction orthogonal to the preceding one. Finally, looking through the slit at 45° he would determine the diagonal and its bisecting line from the line placed at 22°30′, allowing the user to trace geometric figures with 8 or 16 sides, with great precision.