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This description of a vehicle of the nineteenth century has a curious parallel in a narrative that dates from 1,500 years before.

> At Yarmouth the Horse Packet is about 60 feet in length and 18 feet beam. It is worked by four horses in a file which walk in a circus of 18 feet diameter by which they are too much confined and so do only half work. The driving-shaft has two bevelled wheels, one at each end, by which the motion is communicated from the horses to the axle of the paddle wheels of 7 feet diameter. The boat goes at the rate of about six miles an hour.[1]

[1] From D. A. Stevenson, *English Lighthouse Tours* (London, 1946), 59f. See Edward A. Thompson, *A Roman Reformer and Inventor: Being a New Text of the Treatise "De Rebus Bellicis"* (Oxford: Claredon Press, 1952), 54. The author was a lighthouse engineer and uncle of Robert Louis Stevenson, author of *Treasure Island.*

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A Roman author of the fourth century describes his design of a ship powered by waterwheels:

> A Liburnian ship suitable for naval warfare, so large that human weakness more or less precluded its being operated by men's hands, is propelled in any required direction by animal power harnessed by the aid of human ingenuity to provide easy locomotion. 2 In its hull or hold oxen are yoked to machines, two to each, and turn wheels attached to the ship's sides; the spokes project beyond the circumference or rim of the wheels, and, striking the water forcibly like oars as the wheels rotate, work with a wondrous and ingenious effect, their impetus producing locomotion. This same warship, however, owing to its massiveness and the machines working inside it, joins battle with such furious strength that it easily crushes and destroys all opposing warships that come to close quarters with it.[2]

In this study first of all the ancient hydraulics and the progress in this field will be presented. Second, the concept of a ship powered by waterwheels and the design of the Anonymus will be discussed. Subsequently possible connections between the ancient technology and technological progress in modern times shall be considered.

In the ancient world, there were only a limited number of power resources. Human or animal muscle power was predominantly used.[3] One way

[2] "liburnam navalibus idoneam bellis, quam pro magnitudine sui virorum exerceri minibus quodammodo imbellicitas humana prohibebat, quocunque utilitas vocet, ad facilitatem cursus, ingenii ope subnixa, animalium virtus impellit. 2 in cuius alveo vel capacitate bini boves machinis adiuncti adhaerentes rotas navis lateribus volvunt, quarum supra ambitum vel rotunditatem exstantes radii currentibus iisdem rotis in modum remorum aquam conatibus elidentes miro quodam artis effectu operantur, impetus parturiente discursum. 3 haec eadem tamen liburna pro mole sui proque machinis in semet operantibus tanto virium fremitu pugnam capescit ut omnes adversarias liburnas comminus venientes facile attritu comminuat." Text and translation, see Thompson, *Reformer*, 102 and 119–20. For a description of the ship designed by the Anonymus, see Thompson, *Reformer*, 50.

[3] See Kenneth D. White, *Greek and Roman Technology* (New York: Cornell University Press, 1984), 49–57; Brigitte Cech, *Technik in der Antike* (Stuttgart: Wissenschaftliche Buchgesellschaft, 2010), 18–20; Helmuth Schneider, *Einführung in die antike Technikgeschichte* (Darmstadt: Wissenschaftliche Buchgesellschaft, 1992), 40–52; John G. Landels, *Engineering in the Ancient World* (London: Constable and Company, 1998), 9–33.

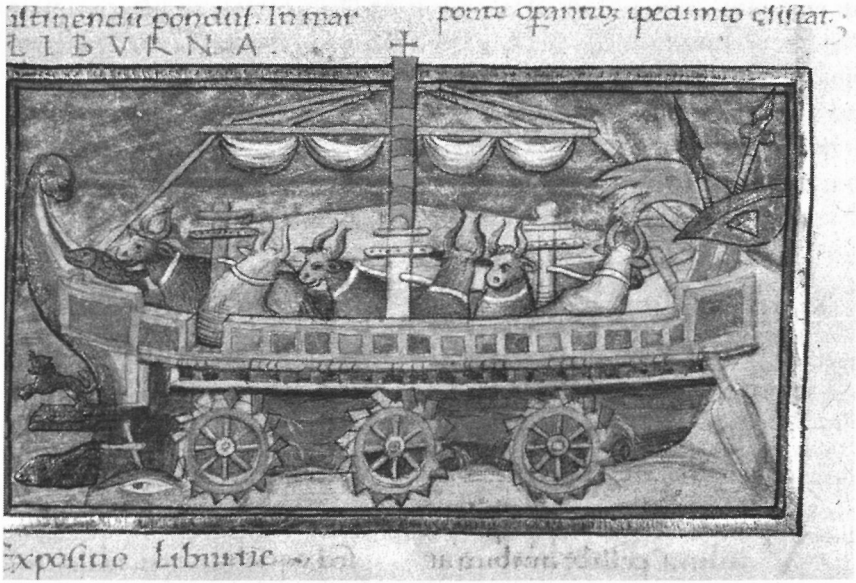

Figure 1: *De Rebus Bellicis* (miniature, fifteenth century).

in which this power was utilized was the mill.[4] A vertical wheel was driven by men/slaves or by animals.[5] The remains of donkey mills have been found in many parts of the Roman Empire, notably in Pompeii.[6]

Apart from the use of animal power, there were also mills powered by water, i.e., waterwheels.[7] The waterwheel was an important source of power

[4] For the basic form of the Roman mill, see Robert J. Forbes, *Studies in Ancient Technology*, vol. 7 (Leiden: Brill, 1965), 89; Cech, *Technik*, 150–53.

[5] Sometimes horses, mostly donkeys, mules and hinnies, oxen and cows, see White, *Technology*, 51–54. For mills driven by men or animal power see John W. Humphrey, John Oleson, and Andrew N. Sherwood, *Greek and Roman Technology: A Sourcebook* (London, New York: Routledge, 1998), 35–37. For the donkey mill see Apuleius, *Golden Ass*, VII,15; see Humphrey, Oleson, and Sherwood, *Technology*, 149–50; for the employment of oxen see Plutarch, *Moralia*, 21, 974e; see Humphrey, Oleson, and Sherwood, *Technology*, 309–10.

[6] For the typical type see White, *Technology*, 65.

[7] For a detailed description see Vitruvius, *De Architectura*, X, 5, 2, see White, *Technology*, 65–67. For the history of the waterwheel, see the chronological survey by John P. Oleson, *Greek and Roman Mechanical Water-Lifting Devices: The History of a Technology* (Dordrecht: Reidel, 1984), 386–98. See also Örjan Wikander, "Archaeological Evidence for Early Water-Mills: An Interim Report," *History of Technology* 10 (1985): 151–79, for an overview of the

in antiquity.[8] In the Mediterranean it most likely came into use starting in the first century. Its usage was manifold. Water-wheels were used to lift water[9] and to power mills. The vertical wheel could be combined with a horizontal wheel. The latter was moved for example by oxen and drove the vertical wheel. This way the water was lifted.[10] The different types of waterwheels are described by the Roman author Vitruvius.[11] The main distinction was between the undershot waterwheel and the overshot waterwheel—the one

scholarly debate. For the use of water power see Klaus Grewe, *Meisterwerke antiker Technik* (Darmstadt: Wissenschaftliche Buchgesellschaft, 2010), 67–71; Örjan Wikander, "Industrial Applications of Water Power," in *Handbook of Ancient Water Technology*, ed. Örjan Wikander (Leiden: Brill, 2000), 401–10; Örjan Wikander, "Sources of Energy and Exploitation of Power," in *Engineering and Technology in the Classical World*, ed. John Peter Oleson (Oxford: University Press, 2008), 141–52; Renate Tölle-Kastenbein, *Antike Wasserkultur* (München: Beck, 1990), 164.

[8] Surprisingly, wind energy—that is, windmills—was rarely used in the ancient world. For the use of wind power see White, *Technology*, 56–57.

[9] There were different methods to raise water. One possibility was the so-called "Archimedean screw"—a device that was allegedly invented by the famous engineer and consisting of a spiral mechanism. There was also the bucket-chain—a wheel with a chain to which buckets were attached. See Vitruvius, *De architectura*, X, 4 and 6. See White, *Technology*, 33–34—also for the description of other devices; for the waterwheel as a lifting device, see Lucio Russo, *Die vergessene Revolution oder die Wiedergeburt des antiken Wissens* (Berlin: Springer Verlag, 2005), 137; Humphrey, Oleson, and Sherwood, *Technology*, 309–12; Forbes, *Studies*, 32–43; Wilson, *Water-Lifting Devices*, 499–510; Cech, *Technik*, 99–111; Schneider, *Technikgeschichte*, 45, 189–90. See Oleson, *Devices*, 325–39, for the wheel with compartmented body or rim.; see also John Oleson, "Water-Lifting," in *Handbook of Ancient Water Technology*, ed. Örjan Wikander (Leiden: Brill, 2000), 229–42; for the water-screw, see Oleson, *Devices*, 291–300; Oleson, "Water-Lifting," 242–51; for the bucket-chain and pot-garland, see Oleson, *Devices*, 350–69; Oleson, "Water-Lifting," 251–63; for the chain-pump Oleson, "Water-Lifting," 263–67; for the saqiya gear, see Oleson, *Devices*, 370; Oleson, "Water-Lifting," 267–72; for the force pumps Oleson, *Devices*, 301–24; Oleson, "Water-Lifting," 272–85; Tölle-Kastenbein, *Wasserkultur*, 34–39, for the different types of water-lifting devices described by Vitruvius (*De Archictectura*, X, 4). For the Archimedean screw, see White, *Technology*, 138 and 140–41; Forbes, *Studies*, 40–41; Landels, *Engineering*, 59–61; Cech, *Technik*, 101–2; Schneider, *Technikgeschichte*, 189–90; Andrew I. Wilson, "Machines in Greek and Roman Technology," in *The Oxford Handbook of Engineering and Technology in the Classical World*, ed. John Oleson (Oxford: University Press, 2008), 353; Tölle-Kastenbein, *Wasserkultur*, 164. For the water-lifting construction in the thermae of Pompeii, see Tölle-Kastenbein, 35–36; for water pumps, see Landels, *Engineering*, 58–83; for water-lifting and drainage see 63–75.

[10] See Russo, *Revolution*, 138–39.

[11] Vitruvius, *De architectura*, X, 7, see also X, 4—see also the inventions of Heron and Ktesibios. White, *Technology*, 32–33, distinguishes between a "bucket-wheel" and a "multiple water-wheel"; see Terry S. Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore: Johns Hopkins University Press, 1983), 41–42.

took water from below, the other from above.[12] The undershot wheel was set in motion by the force of the water.[13] Wheel blades were attached to increase efficiency.[14] The overshot wheel is judged by Reynolds to be more efficient but also more expensive. Water flew from above into buckets attached to the wheel; by the weight of the filled containers the wheel was set in motion.[15] For the overshot waterwheel to be working a more elaborate construction was necessary, for example the building of a conduct or a race.[16]

The waterwheel seems to have developed from a combination of the ordinary millstone and water-lifting devices which were powered by men or animals.[17] Reynolds, however, regards it as more probable that the model for this development was "the water lever, the noria, and the primitive horizontal water-mill."[18] It should be noted, that the waterwheel was a rather late de-

[12] For the different types of wheels—vertical and horizontal—see Reynolds, *Water Wheel*, 9–20; Forbes, *Studies*, 42. Forbes, *Studies*, 92, sees the undershot-wheel as "the type common to Antiquity"; he states, however, that it was "less efficient." He regards the wheel described by Vitruvius as "probably the first to be designed and built," but emphasizes also the deficiencies of this type. For the mechanism of mills see Örjan Wikander, "The Water-Mill," in *Handbook of Ancient Water Technology*, ed. Örjan Wikander (Leiden: Brill, 2000), 371–400. See also Wikander, "The Water-Mill," 373–78, for the types of wheels (esp. for the literary sources, the archaeological finds, the question of efficency), 384–92; Wikander, "Sources," 144–48; Cech, *Technik*, 97–98; Tölle-Kastenbein, *Wasserkultur*, 17–20; Landels, *Engineering*, 16–26 (discussing the finds from Barbegal and the Athenian agora). For reconstructions of waterwheels, lifiting devices, and the archaeological finds, see Oleson, *Devices*, xv–xx; see also Oleson, "Water-Lifting," 217–302; for depictions and reconstructions of waterwheels, see also Tölle-Kastenbein, *Wasserkultur*, 162–63.

[13] For the powering of waterwheels by running water see Russo, *Revolution*, 142–47. See Strabo, XII, 3, 30; Anthol. Graeca, IX, 418; Vitruvius, *De architectura*, X, 5. In the case of the first water was raised by a wheel-mechanism or a wheel was set in motion by running water, in the second case a wheel was driven by a stream of water being lead on it from above.

[14] See Reynolds, *Water Wheel*, 11.

[15] Reynolds, *Water Wheel*, 11.

[16] See Reynolds, *Water Wheel*, 11.

[17] For a discussion of the relationship between primitive constructions and the vertical waterwheel, see Reynolds, *Water Wheel*, 14–16. He for example refers to the descriptions found in work of Philo. As he points out there a depictions of waterwheels in later manuscripts of this author's works, but it is not sure if these pictures were already part of the original edition of the *Pneumatica*. As Reynolds also emphazises, "there is a gap of almost two centuries between Philo and the next extant reference to an undershot wheel, and a gap of around four centuries between Philo and the next clear evidence of an overshot wheel."

[18] See Reynolds, *Water Wheel*, 11, for the instruments see 11–15. Reynolds, *Water Wheel*, 20, comes to the conclusion that "the vertical undershot water-mill, the horizontal water-mill, and the *noria* appeared almost simultaneously in the Mediterranean world in the first century B.C."; see also Russo, *Revolution*, 143–44.

velopment.[19] The earliest references to possible waterwheels can be found for example in Strabo:

> Now this city (Magnopolis) is situated in the middle of the plain, but Cabeira is situated close to the very foothills of the Paryadres Mountains about one hundred and fifty stadia farther south than Magnopolis, the same distance that Amaseia is farther west than Magnopolis. It was at Cabeira that the palace of Mithridates was built, and also the water-mill; and here were the zoological gardens, and, near by, the hunting grounds, and the mines. (Strabo, XII, 3, 30)[20]

According to Reynolds, the first mills of this type may date back as early as the times of Pompey, but emphasizes that a reconstruction of the mechanism Strabo describes is difficult.[21] An early reference to a water mill can also be found in a poem of Antipater:

> Cease from grinding, ye women who toil at the
> Mill; sleep late, even if the crowing cocks announce
> The dawn. For Demeter has ordered the Nymphs to
> Perform the work of your hands, and they, leaping
> Down on the top of the wheel, turn its axle which,

[19] For the chronological order of development see the overview of the scholarly debate—and the discussion of possible links with inventions in India and China—by Reynolds, *Water Wheel*, 20–30. Reynolds, 25–26, argues that the undershot mill was a derivative of the noria and that the vertical undershot mill is a "a blend of three earlier inventions—the vertical water-powered wheel of the the noria, the rotary millstones of the hand-powered quern, and gearing." He assumes that the undershot water mill was invented in Asia Minor and states that the overshot vertical wheel was a development later than the *noria*, the undershot water mill and the horizontal water mill. For the development of the water mill, see White, *Technology*, 196–99; Forbes, *Studies*, 41–43; see also 91 for the Roman type of mill. See Wikander, "The Water-Mill," 394–400, for the relevant sources.

[20] For the possible water mills in the palace of Mithradates VI, see Reynolds, *Water Wheel*, 16–17; Russo, *Revolution*, 142; Örjan Wikander, "The Use of Water-Power in Classical Antiquity," *Opuscula Romana* 13.7 (1981): 93; Forbes, *Studies*, 88; Landels, *Engineering*, 17; Schneider, *Technikgeschichte*, 46; Lynn White, Jr., *Medieval Technology and Social Change* (Oxford: Claredon Press, 1963), 80; for the dating of the first mill to the first century (on the basis of the archaeological evidence), see Wikander, "The Water-Mill," 397–98; see Wikander, "Sources," 142. Wikander assumes, that the water mill may have been invented in the third century BC but technical problems prevented a realization on a larger scale.

[21] See Reynolds, *Water Wheel*, 16–17.

> With its revolving spokes, turns the heavy concave
> Nisyrian mill-stones. We taste again the joys of the
> Primitive life, learning to feast on the products of
> Demeter without labor.
>
> (Antipater of Sidon, Anth. Palat., IX, 418)

He describes a mechanism which could have been a waterwheel or a water mill.[22] As Russo points out, the description in Antipater corresponds to a vertical waterwheel.[23] There are two more authors referring to constructions powered by water. One is a short passage in Lucretius, where he compares the movement of the heavens to that of wheels: "Or else that another air flows below to lift up the circle in the opposite direction, just as we see rivers turn wheels and buckets" (Lucretius, V, 516).[24] Reynolds assumes that Lucretius is describing a mechanism like the noria.[25] A more specific description of mill wheels can be found in Vitruvius, *De Archictectura*, X, 5, 1–2:[26]

> Wheels are used in rivers in the same way as described above. Round the outside, paddles are fixed, and these, when they are acted on by the current of the river, move on and cause the wheel to turn. In this fashion they draw up the water in buckets and carry it to the top without workmen to tread the wheel. Hence, being turned by the force of the river only, they supply what is required.
>
> Mill wheels are turned on the same principle, except that at one end of the axle a toothed drum is fixed. This is placed vertically on its edge and turns with the wheel. Adjoining this larger wheel there is a second toothed wheel placed horizontally by which it is gripped. Thus the teeth of the drum which is on the axle, by driving the teeth of the horizontal drum, cause the grind-

[22] Reynolds, *Water Wheel*, 17; Russo, *Revolution*, 142–43; Forbes, *Studies*, 88, Lynn White, *Medieval Technology*, 80; Schneider, *Technikgeschichte*, 46; Landels, *Engineering*, 17; Wikander, "Sources," 142, 144, 148; Wikander, "The Water-Mill," 375.

[23] Russo, *Revolution*, 143.

[24] For this passage see Wikander, *Use*, 92–93; Forbes, *Studies*, 89; Schneider, *Technikgeschichte*, 46; Landels, *Engineering*, 17–18.

[25] See Reynolds, *Water Wheel*, 17.

[26] See Reynolds, *Water Wheel*, 17–18; see also Russo, *Revolution*, 143, arguing against the opinion held by Bloch; Wikander, *Use*, 93; Forbes, *Studies*, 89; for the description of Vitruvius, see Lynn White, *Medieval Technology*, 80–81; Wikander, "The Water-Mill," 373–74; Schneider, *Technikgeschichte*, 45–46; Wikander, "Sources," 142.

> stones to revolve. In the machine a hopper is suspended and supplies the grain, and by the same revolution the flour is produced.

He was probably depicting an undershot water mill and a noria.[27] There are also a few depictions of waterwheels. Most of them date to the period of the later empire.[28] As Reynolds explains, the earliest evidence of the use of the overshot waterwheel is a painting dating to the third century.[29] It is conspicuous that the water mill is very rarely mentioned in ancient sources.[30] The above-mentioned authors are the most direct reference to this device.[31] Reynolds assumes that this results from the fact that the waterwheel "was not at first widely accepted." In this context he points to the statement of Vitruvius that machines like that were "rarely employed."[32] In the time of the Roman Empire the waterwheel obviously still was a rarity. It is mentioned only by a few authors, for example Pliny the Elder, who says about water mills: "Throughout the greater part of Italy, however, they employ a pestle that is only rough at the end, and wheels turned by water, by means of which the corn is gradually ground" (Pliny, *Naturalis Historia*, 18, 97).[33] Reynolds also sees an indirect proof for the rarity of water mills in a passage of Suetonius. The ancient biographer reports that in Rome a famine broke out when the emperor Caligula confiscated the animals who were powering the mills of the Roman bakeries:

> When he was in Gaul and had sold at immense figures the jewels, furniture, slaves, and even the freedmen of his sisters who had

[27] Reynolds, *Water Wheel*, 17–18. For the *noria* see also Wikander, *Use*, 92–94.

[28] See Reynolds, *Water Wheel*, 18–19.

[29] Reynolds, *Water Wheel*, 18, points to the archaeological evidence, i.e., remnants of structures related to water mills. For an overview over the archaeological evidence, see White, *Technology*, 200–201.

[30] Örjan Wikander, "Water-Mills in Ancient Rome," *Opuscula Romana* 12.2 (1979): 13–36, however, stresses that the use of the water mill might have been rather widespread already in the first century AD and points, for example, to the commentary of Pomponius Laetus to Vergil, *Moretum*, V, 39, in which he mentions water mills for the period shortly before the reign of Augustus.

[31] For an extensive overview over the sources Oleson, *Devices*, 15–125; for a catalogue of the relevant papyri, 126–46; see also Oleson, "Water-Lifting," 218. For reference in ancient literature see Wikander, *Use*, 92–93, who refers also to Philon, *Pneumatica*, 65; Cato, 11, 3; *Scriptores Historiae Augustae*, 24, 5, as possible mentions of water mills.

[32] Reynolds, *Water Wheel*, 30.

[33] See Reynolds, *Water Wheel*, 30 (also for evidence in the Talmud); Wikander, "Sources," 152.

> been condemned to death, finding the business so profitable, he sent to the city for all the paraphernalia of the old palace, seizing for its transportation even public carriages and animals from the bakeries; with the result that bread was often scarce at Rome and many who had cases in court lost them from inability to appear and meet their bail. (Suetonius, *The Twelve Caesars*, 39)

Reynolds concludes: "Had water-mills rather than animals been grinding a significant portion of Roman grain, this would not have happened."[34] Although there are not many references to such devices in literature, archaeological evidence attests to the existence of waterwheels.[35] The use of water mills seems to have become more widespread from the third century onward.[36] Thompson points to an increasing amount of evidence starting in the later fourth century.[37] An interesting testimony of the use of water mills can also be found in the edict of Diocletian, with respect to the prices for various goods. Mills are also mentioned with distinctions between the different types of mills. The edict lists mills powered by horses, donkeys, by water and manpower—and their respective prices: "Mill driven by horses—1500 denarii; Mill driven by donkeys—1250 denarii; Water-mill—2000 denarii; Handmill —250 denarii" (Diocletian, edict on prices 15, 52ff.).[38] As Reynolds points out, the water mill is mentioned in third place and concludes that it might not have been as important as the mills powered by animals but already more

[34] Reynolds, *Water Wheel,* 30. See also Thompson, *Reformer*, 48–49; Wikander, "Water-Mills," 13–14, 21; Forbes, *Studies*, 96; Schneider, *Technikgeschichte*, 46–47.

[35] See Reynolds, *Water Wheel*, 30, Forbes, *Studies*, 93–96. (for the finds in Venafro, Barbegal, on the Agora). For relevant archaeological finds, see also the catalogue of sites in Oleson, *Devices*, 172–217; Wikander, "The Water-Mill," 374–78; Wikander, "Sources," 142–50; Wikander, *Archaeological Evidence*, 151–79, for an overview over the finds and for possible components of mills; also Wilson, *Machines*, 355–57. For the archaeological evidence from Italy and the provinces (remains of wheels, water channels, dams, etc.) and the construction of the waterwheels, see Reynolds, *Water Wheel*, 35–44. See also Wikander, *Use*, 93–95 (pointing to mosaics in Apameia and Constantinople and discussing the finds from the Baths of Caracalla); Wikander, "Water-Mills," 13–36 (for the water mills in Rome); for wall paintings from Rome showing the water mill, see 23. For the mills in the Baths of Caracalla, see Wikander, "Sources," 147; see also Wikander, *Use*, 94–95; Forbes, *Studies*, 97.

[36] See Reynolds, *Water Wheel*, 30.

[37] Thompson, *Reformer*, 48, even states that "it was not until the middle of the fourth century that the water-mill began to be used in the city of Rome." As he states the number of references to water mills increases from that time on until the seventh century.

[38] See Wikander, "Sources," 143; Schneider, *Technikgeschichte*, 47.

widespread than handmills.[39] From the third century onward there are again numerous references and archaeological finds pointing to the use of waterwheels.[40] It is for example mentioned that a certain Metrodōrus in the fourth century introduced the use of water mills in India.[41] Ausonius in the fourth century also makes mention of water mills:

> Renowned is Celbis for glorious fish, and that
> Other, as he turns his mill-stones in furious revolutions
> And drives the shrieking saws through smooth
> blocks of marble,
> Hears from either bank a ceaseless din.[42]
> (Ausonius, Moselle, 361–64)

The mechanism Ausonius describes was obviously used to drive saws.[43] The authenticity of these verses is doubtful,[44] however, although there is evidence that mechanical saws existed.[45] A passage in Procopius seems to be more reli-

[39] Reynolds, *Water Wheel*, 31.

[40] For the increase in evidence from the fourth century onward, see Forbes, *Studies*, 96; he points also to the introduction of the water mill in India by the Persian Metrodoros in the time of Constantine.

[41] See Reynolds, *Water Wheel*, 31.

[42] Reynolds however, *Water Wheel*, 31, regards this passage as being "questionable." For the dating see also John H. W. G. Liebeschütz, "Realism and Phantasy: The Anonymus *de rebus bellicis* and His Afterlife," in *Decline and Change in Late Antiquity*, ed. John H. W. G. Liebeschütz (Aldershot: Ashgate, 2006), 132–34, differing from Hartwin Brandt, *Zeitkritik in der Spätantike. Untersuchungen zu den Reformvorschlägen des Anonymus De Rebus Bellicis* (München: Becksche Verlagsbuchhandlung, 1988), 135–62, who dates the work in to the fifth century. See Russo, *Revolution*, 294. Örjan Wikander, "Ausonius' Saw-Mills—Once More," *Opuscula Romana* 17 (1989): 185–90, sees the passage as authentic, discussing technical details and problems; he also designs a reconstruction of the mechanism.

[43] For the driving of saws by waterwheels in Ausonius, *Mosella*, 359–64, see Humphrey, Oleson, Sherwood, *Technology*, 33–34; Wilson, *Machines*, 357–58. See Wikander, "Sources," 150–51, who also points to Gregory of Nyssa, *In Ecclesiaten*, 3, 656; Jacques-Paul Migne, *Amm. Marc.*, 23, 4, 4, and discusses the finds from Jarash (dating to the sixth century), Ephesus (dating to the seventh century), Pamulale (dating to the second or third century).

[44] See Dennis L. Simms, "Water-Driven Saws, Ausonius, and the Authenticity of the Mosella," *Technology and Culture* 24 (198): 635–43, for the question of authenticity and dating. See Wikander, *Use*, 99–100. See Wikander, *Industrial Applications*, 401, 404–5; Lynn White, *Medieval Technology*, 82–83; Forbes, *Studies*, 96; Schneider, *Technikgeschichte*, 48–49, Landels, *Engineering*, 25.

[45] See Grewe, *Meisterwerke*, 67–71, for the depiction of a sawmill powered by water on a gravestone from Phrygia, dating to the third century. The deceased refers to himself as

able. This author, writing in the sixth century, refers to a greater number of water mills on the Janiculum:

> And opposite this flat ground, across the Tiber, it happens that there is a great hill where all the mills of the city have been built from of old, because much water is brought by an aqueduct to the crest of the hill, and rushes thence down the incline with great force.[46]

The Christian author Prudentius already mentions these mills at the end of the fourth century:[47]

> Who comes hungry to the shows in the great circus?
> What district of Rome is enduring the horrors of want because the steps are empty?
> What mill on Janiculum is silent and at rest?
> (Prudentius, *Contra orationem Symmachi*, II, 950)

Several larger facilities are attested to in Rome and other parts of the Empire.[48] As Wikander points out the first mills such as those on the Janiculum and in Arles were rather exceptions, although "not uncommon."[49]

A certain degree of specialization of mills and milling can be observed. Already from the first century onward professional millers begin to appear in the sources.[50] There is also evidence of the involvement of the imperial

"Daedalus." See Grewe also for archaeological evidence for stone cutting saws dating to the sixth century.

[46] Procopius, *De Bello Gothico*, V, 19, 8. See Reynolds, *Water Wheel*, 31.

[47] See Reynolds, *Water Wheel*, 31; Wikander, "Water-Mills," 16; Schneider, *Technikgeschichte*, 47, for the quarter of the millers on the Janiculum, with reference to *Codex Theodosianus*, XIV, 15, 4 and Procopius, *De.Bello Gothico*, V, 19, 8.

[48] See Wikander, "Sources," 149–50, for the mills in Barbegal/Arles and on the Janiculum; see also Wikander, "Water-Mills," 20–24; Wikander, "The Water-Mill," 393–94; Landels, *Engineering*, 18; Schneider, *Technikgeschichte*, 47, illustration no. 4; Grewe, *Meisterwerke*, 67, for Barbegal/Arles and Chimtou; for Chimtou see Schneider, *Technikgeschichte*, 48; see also Andrew Wilson, "Water-Power in North Africa and the Development of the Horizontal Water-Wheel," *Journal of Roman Archaeology* 8 (1995): 499–510; for the different types of mills and example, see 503.

[49] Wikander, "Sources," 150.

[50] See Forbes, *Studies*, 97, for the *molitores* or *molendarii*; see Wikander, "Water-Mills," 23; Oleson, *Devices*, 392–97; Tölle-Kastenbein, *Wasserkultur*, 165, with reference to Pliny,

central administration. In an edict the emperors Honorius and Arcadius defined regulations to ensure water inflow for these mills.[51] Reference to mills in the countryside can also be found. Palladius mentions them in his book on agriculture.[52] Another example is the mentioning of a water mill in the neighborhood of Subiaco.[53]

There are a number of archaeological finds pointing to the use of water mills, for example a mosaic from Byzantium and structures found on the Athenian agora.[54] Reynolds emphazises in particular the importance of finds in Athens. He notes that Athens was a rather unimportant town in the fifth century. In his opinion, a water mill in a place like that proves the widespread use of this device.

There are also various references to water mills in the imperial jurisdiction of the fifth and sixth century.[55] Reynolds mentions an edict of the Byzantine emperor Zeno, later asserted by Justinian, by which it was forbidden to appropriate water from the public conducts for water mills on private ground. He also points to several references to water mills in the Pandects of Diocletian. In addition, a reference to a "water wheel engineer" in an inscription from Sardis also exists.[56] Another inscription mentions hydraulic

Naturalis Historia, XVIII, 107–8. Wikander, "Water-Mills," 15–23. See Forbes, *Studies*, 96, also discussing the information in Sextus in his "Topography" that there were two hundred mills around the year 300 AD (although not differentiating between water mills and those powered by animals).

[51] See an edict of Arcadius and Honorius—*Codex Theodosianus*, XIV, 15, 4. See Reynolds, *Water Wheel*, 31; Wikander, "Water-Mills," 15–16. See also the Edict of Dynamis (CIL VI,1711), see Wikander, "Water-Mills," 16. See Forbes, *Studies*, 96–97. For the increase of the numbers of mills on the Janiculum and the edict of Honorius and Arcadius, with reference to Prudentius, *Contra Symmachum*, II, 949–50; Procopius, *De Bello Gothico*, I, 19.

[52] See Reynolds, *Water Wheel*, 31; Schneider, *Technikgeschichte*, 47; Forbes, *Studies*, 97.

[53] Reynolds, *Water Wheel*, 31.

[54] See Reynolds, *Water Wheel*, 31. For the mill on the agora see Forbes, *Studies*, 91–96.; Wikander, "Sources," 147; Landels, *Engineering*, 18.

[55] Reynolds, *Water Wheel*, 31. See Forbes, *Studies*, 97, for the edicts of Zenon, Theoderic, Justianus, the laws in the Digests of Justinian, the Visigoth Laws.

[56] See Reynolds, *Water Wheel*, 31. He however acknowledges that this person could have been responsible for the building of wheels for water-raising. See Wikander, "The Water-Mill," 398, for the epigraphical evidence. For a collegium of water millers in Hierapolis (Tullia Ritti, Klaus Grewe, and Paul Kessener, "A Relief of a Water-Powered Stone Saw Mill on a Sarcophagus at Hierapolis and Its Implications," *Journal of Roman Archaeology* 20 [2007]: 138–63) and similar evidence from Günzburg (CIL III 5866); see also Wikander, "Sources," 148; Russo, *Revolution*, 294; see Forbes, *Studies*, 96, for an epitaph in Sardes.

engineers in the city of Arles.[57] Waterwheels were, as already mentioned, also used for drainage.[58]

It is difficult to determine why water power was widely used only in the period of late antiquity.[59] Reynolds suggests several possible reasons for the late implementation of the waterwheel on a larger scale.[60] First he stresses the "attitude of the ruling class towards nature and towards manual labor."[61] He points to the fact that according to ancient belief it was inappropriate for men to try to interfere in the order established by the gods.[62] Secondly Reynolds mentions "the economic mentality of the ancient world," that is, the disdain for manual labor. In his opinion this attitude inhibited larger investments in technological devices—the Roman landowners preferred the cheaper mills powered by animals or men. Reynolds emphazises that the Greeks and Romans "considered aesthetic improvement and the performance of tasks otherwise impossible or nearly impossible to be the proper domain of technology."[63] Because the water mill only increased the quantity not the quality of the flour and only reduced the required workforce, it would not have been considered a valuable improvement. Reynolds also considers "the geography of the Mediterranean" important, i.e., the fact that many rivers are small and artificial constructions would have been necessary.[64] The most

[57] CIL XII,722; see Oleson, "Water-Lifting," 295.

[58] For the Roman technology of drainage (for example of mines) see Forbes, *Studies*, 46–49.

[59] Forbes, *Studies*, 98–99, for the fact that the theoretical knowledge was available but not used.

[60] Reynolds, *Water Wheel*, 32–35.

[61] See also Kevin Greene, *Inventors, Invention, and Attitudes toward Technology and Innovation*, in Örjan Wikander, ed., *Handbook of Ancient Water Technology* (Leiden: Brill, 2000), 800–18. for the attitude toward technology; see also Wikander, *Industrial Application*, 408–10. Forbes, *Studies*, 98–105, sees the following reasons for the late application of mills: the geography of the Mediterranean, the lack of incentive for mechanization or industrialization, the contempt for manual labor, the concentration of wealth in the hand of few, the absence of mass production.

[62] For the question why the Romans rarely developed new technologies see Thompson, *Reformer*, 44–50.

[63] For the Roman attitude toward science and technology see also Russo, *Revolution*, 269–75; Oleson, "Water-Lifting," 287–96; Oleson, *Devices*, 398–410. Concerning the factors inhibiting technical advance he stresses the low opinion of labor, the problem of investment into technology, the Roman conservatism, the deficiencies of the energy-sources, of the materials and the relevant techniques. For the attitude toward experiments and innovations see Humphrey, Oleson, and Sherwood, *Technology*, 588–97.

[64] See also Wikander, "Water-Mills," 14–15. Wikander, "Sources," 143, stresses the necessity of constant water supply, i.e., of an aquaeduct or a channel (with reference to the mills

important factor which probably hindered the spreading of the use of waterwheels was undoubtedly the labor surplus, the fact that finding workers or slaves never constituted a problem.[65] Labor-saving advancements were therefore unnecessary. As Reynolds points out—with reference to Diocletian's edict—the initial costs for a water mill were relatively high, even if the labor costs were lower.[66] Water mills were therefore uneconomical, especially the earlier types of this device which exhibited deficiencies. This situation changed in Late Antiquity. Thompson states that following the invention of the water mill "there was no widespread need" for its use.[67] In his opinion this changed in Late Antiquity because of the shortage of workforce: "The old invention thereupon came into its own, and was applied in some measure by the Roman government, though it was only exploited fully under the barbarian kings."[68] Indeed by the time of the later empire the evidence for the existence of water mills increased.[69] It is therefore no coincidence that most of the literary allusions to the waterwheel date to this period.[70] The late antique author Palladius directly mentions that shortage of labor could be one reason for the implementation of a water mill:[71] "If there is plenty of water, the pistrina ought to receive what comes from the bath, that, water mills being

on the Janiculum, in Barbegal and Haltwistle. For the dams see Wikander, "The Water-Mill," 379–83.

[65] See Reynolds, *Water Wheel*, 34. For the importance of slave labor see Forbes, *Studies*, 81–84. See Donald Cardwell, *Wheels, Clocks, and Rockets. A History of Technology* (New York: Norton, 2001), 25–29, for the strengths and weaknesses of Roman science and the importance of slavery.

[66] For problem of the dependence of the water mill on an aquaeduct see Reynolds, *Water Wheel*, 44–45.

[67] Thompson, *Reformer*, 48.

[68] Reynolds, *Water Wheel*, 45, considers several reasons, why the use of water power became more widespread in Late Antiquity. In his opinion the rise of Christianity was one important factor as the Christian view of the world and nature was different from the pagan one. Second, Reynolds points to the increasing labor shortage, partly due to the decreasing supply of slaves and decline in population (also referring to the proposals of the Anonymus). See also Forbes, *Studies*, 103–5, for the new attitude toward labor and nature in Late Antiquity which he attributes to the influence of Christianity.

[69] For the spread of the use of water mills in the Empire, see Russo, *Revolution*, 294–95—he for example points to the existence of a society of water millers in Hierapolis; see also Wikander, "The Water-Mill," 398.

[70] See for example the mentions of water mills by Cassiodor, *Variae*, III, 31.2, see Wikander, "Water-Mills," 16.

[71] See Reynolds, *Water Wheel*, 45; Forbes, *Studies*, 97, sees labor shortage as the reason for the increase in the use of the water mill. Wikander, "Sources," 150, also stresses the importance of labor-saving measures from the third century onward.

constructed there, corn may be ground without the labour of men or cattle" (Palladius, *Opus Agriculturae*, 1, 42).

The technique of the mills was obviously refined in later times.[72] A number of waterwheels were also combined.[73] A famous example of a highly sophisticated and complex construction is the installation at Barbegal, consisting of sixteen water mills which are cascaded.[74] The more widespread use of water mills from the third century onward becomes evident. It is more difficult to draw a connection between shipbuilding and the use of water-powered wheels—and thereby a possible model for the construction described by the Anonymus.[75]

In antiquity there were two ways of powering ships.[76] On the one hand—and this is already depicted on vases dating from the ninth and eighth century BC—ships were powered by oarsmen. In order to achieve maximum speed as many banks of oars as possible were set behind one another or—as in case of the trireme—one above the other. Sails were also used, although pure sailing vessels were rare. Wind power was only used as an additional means of powering ships.[77]

A passage in Procopius can be cited as a possible example of an early combination of ships and waterwheels.[78] The author describes the siege of Rome by gothic troops. The Goths destroyed the aqueducts and thereby disrupted the water inflow to Rome. As in the times of Caligula the supply situation in the capital became critical. Reynolds sees this again as evidence of

[72] Reynolds, *Water Wheel*, 45, discerns also an "increased sophistication in late Roman hydropower technology."

[73] See the construction for the lifting of water/drainage found at Rio Tinto; see Russo, *Revolution*, 291–92.

[74] See Russo, *Revolution*, 293–94, dating it to the second century AD; Reynolds, *Water Wheel*, 34, 39–41; Forbes, *Studies*, 93–95; Cech, *Technik*, 98–99; Tölle-Kastenbein, *Wasserkultur*, 153, 164; Landels, *Engineering*, 18–23.

[75] See Reynolds, *Water Wheel*, 31–32.

[76] For ancient seafaring and shipbuilding see the fundamental work of Lionel Casson, *Ships and Seafaring in Ancient Times* (Austin: University of Texas Press, 1994); see also Hans D. L. Viereck, *Die römische Flotte* (Herford: Koehler, 1975). For ancient shipbuilding see White, *Technology*, 141–56; 210–14; Humphrey, Oleson, and Sherwood, *Technology*, 442–62.

[77] For the only direct reference to a windmill see Heron, *Pneumatics*, I,43; see Humphrey, Oleson, and Sherwood, *Technology*, 26–27. For the evidence for windmills see Russo, *Revolution*, 144; Michael J. T. Lewis, "The Greeks and the Early Windmill," *History of Technology* 15 (1993): 141–89; Aage G. Drachmann, "Heron's Windmill," *Centaurus* 7 (1961): 145–51; Wikander, "Sources," 152–54; Landels, *Engineering*, 26–27; Forbes, *Studies*, 115–19; Lynn White, *Medieval Technology*, 85–88.

[78] Procopius, *De Bello Gothico*, V, 19, 19ff.

the reliance on water mills in this period.[79] To relieve the situation the Roman commander Belisarius ordered the building of a special type of ship, i.e., mills, with undershot waterwheels connected to boats.[80] Although the Goths tried to destroy these mechanisms the Romans succeeded in keeping them working and therefore had enough flour.[81] The principle of attaching waterwheels to ships was already known although not for moving the ship itself.[82]

The first extensive design of a ship powered by paddle wheels is cited by the above mentioned author in the fourth century.[83] The work is a letter to the emperor. The author proposes a number of improvements on the military sector. These would strengthen the imperial army; they also represented a reaction to the increasing threat of barbarian invasions. The author hoped for—as he himself remarks—permanent fame. The work has, however, been passed down under the title "Anonymus de rebus bellicis."[84] In his work the author makes several reform proposals—with respect to the currency, the fiscal policy and the management of the empire, the legislation and also the organization and armament of troops. In

[79] Reynolds, *Water Wheel*, 32; Wikander, "Water-Mills," 16.

[80] Procopius, *De Bello Gothico*, V, 19. He describes that the aequeducts were destroyed and therefore the mills were not working anymore. Because of the siege the Romans had no animals to spare for operating the mills. In this situation Belisarius had the idea of securing two boats to the banks of the river, placing them in the middle of the stream near a bridge. To each of the boats two mills were attached and additional boats were added, one after the other. In this way a sequence of water mills was constructed and flour could be ground. The boat mills were then destroyed by the Goths by throwing trees into the river. Belisarius, however, attached iron chains to the bridge, which stretched across the river and prevented objects of crashing against the mills and the enemy from getting near the city. The mills were then reconstructed. As Procopius remarks, the mills were also used in the following years. See Reynolds, *Water Wheel*, 32–33, "The wheels on these mills were mounted between two boats anchored several feet apart at a point near a bridge where the current was swift." Forbes, *Studies*, 105–6; Schneider, *Technikgeschichte*, 47–48; Thompson, *Reformer*, 50; Wikander, "Water-Mills," 29–32. He states that the mills were probably not newly built but transferred from the Janiculum.

[81] See Reynolds, *Water Wheel*, 32.

[82] Thompson, *Reformer*, 51, stresses that the construction of the mechanism itself constituted no problem as the principle was that of the water mill.

[83] For an overview over the scholarly debate see Brandt, *Zeitkritik*, 1–10. See Santo Mazzarino, "Il De Rebus Bellicis e la Gratiarum Actio di Claudio Mamertino," in *Studi di storiografia antica in memoria di L. Ferrero*, ed. Leonardo Ferrero (Turin: Bottega d'Erasmo 1971), 209–14; Wilson, *Machines*, 358.

[84] For the problem of the title of the work see Thompson, *Reformer*, 84–85, who argues that it is probably the original one. See also Alan E Astin, "Observations on the De rebus bellicis," in *Studies in Latin Literature and Roman History 3*, ed. Carl Deroux (Coll. Latomus 180) (Bruxellex: Latomus, 1983), 420–22.

this context he presents several innovations.[85] The descriptions of the Anonymus are illustrated by drawings which have also been passed down—although it is a matter of debate how faithful the medieval reproductions of the original drawings are.[86] With respect to the author's lifetime and the date of composition of his work, different dates have been proposed.[87] As Thompson points out, the author mentions Constantine demonstrating that he lived later than his reign. On the other hand, Thompson emphasizes that the barbarians obviously had not yet crossed the border of the Roman Empire in larger numbers. He therefore dates the work between 337 and 378 AD. Because of the reference to two emperors in the preface he dates the work to the time of Valentinian I and Valens, i.e., 366–75 AD.[88] This dating seems indeed most likely.

[85] See Liebeschütz, "Realism," 120–25, for the introduction and the character of the work; see Astin, "Observations," 390–401; for the purpose of the work see Burckhardt Meißner, *Die technologische Fachliteratur der Antike* (Berlin: Akademie Verlag, 1999), 84–85, 99; for the work in general 277–83. For the inventions Astin, "Observations," 408–14; Liebeschütz, "Realism," 125–32. He regards them not as a serious proposals of reforms. As he stresses, "the problems which the author proposed to solve are real enough, but the solutions are playful or semi-playful." In his opinion "the pamphlet was intended to arouse interest, to stimulate, and to amuse" and he sees humor pervading the whole work.

[86] See Thompson, *Reformer*, 1. He speaks of "more or less faithful copies." For the problem of the illustrations see also Thompson, *Reformer*, 16–17, and Robert Ireland ed., *Anonymi Auctoris Libellus De Rebus Bellicis* (Leipzig: Teubner, 1984), Praef. XXVIII–XXX.; J. J. G. Alexander, "The Illustrations of the Anonymus, De Rebus Bellicis," in *De Rebus Bellicis*, ed. Mark W. C. Hassall (Oxford: BAR, 1979), 11–15.

[87] For the scholarly debate, see Thompson, *Reformer*, 1–6. See also Alan Cameron, "The Date of the Anonymus," *De Rebus Bellicis*, ed. Mark W. C. Hassall (Oxford: BAR, 1979), 1–10, who dates the Anonymus more precisely to the year 368/9 AD. For the discussion of the dating see also Brandt, *Zeitkritik*, 135–62. He himself dates the Anonymus in the first half of the fifth century. Due to the character of his proposals he more specifically suggests a dating in the reign of Valentinian III. Brandt, 157–62, argues that the Anonymus had to be dated rather to the fifth century due to the specific characterization of the barbarians and the reference to impending wars. Brandt, 154–55, points to the fact that the Anonymus puts emphasis on naval warfare and that he argues that his liburna will be very applicable for this. Brandt states that the size of the ship designed by the Anonymus does not correspond to the Roman ships of the fourth century. He further argues that in the time of the Anonymus there must have been naval battles of a kind which required ships of such dimensions—in his opinion this was the case only in the fifth century. Brandt here confuses the statement of the Anonymus that his ship was so great that it had to be powered not by men but by oxen—an attempt to advertise his invention—with a description of the realities of warfare of his time. He also probably underestimates the originality of the author. Humphrey, Oleson, and Sherwood, *Technology*, 34, characterize him as an "imaginative Byzantine bureaucrat who wrote the following passage around 370."

[88] See Thompson, *Reformer*, 2, also for a refutation of a dating in the time of Arcadius and Honorius. For a discussion of the dating, see Barry Baldwin, "The *De rebus bellicis*," *Eirene*

Concerning the identity of the author, Thompson convincingly argues that he was living in the Western part of the Empire—because he wrote in Latin—and more precisely—because of his interest in the frontier regions in the Illyrian Prefecture.[89] Thompson assumes that the author was probably not a member of the highest class; despite his obvious interest in military affairs. Instead, he considers him "a knowledgeable civilian"—pointing to the fact that in XII,1 he distances himself from the military.[90] Because of his attitude toward Constantine and the lack of typical Christian statements, Thompson regards him as a pagan writer.[91] The personal background of the author is disputed. Meißner regards him as a "Verwaltungsfachmann."[92] Liebeschütz characterizes him as a "former bureaucrat, probably a civilian."[93] Baldwin regards him as a "man of leisure." In his opinion he may have been a retired official.[94]

16 (1978): 23–39; Ireland, *Rebus Bellicis*, Praef. V–VIII; Otto Seeck, s.v. "Anonymi (3)," in Pauly-Wissowa's *Realencyclopädie* (1894), 1:2325; Astin, "Observations," 394–97; Liebeschütz, "Realism," 132–34. Rudolf Schneider, *Anonymi de rebus bellicis liber* (Berlin: Weidmannsche Buchhandlung, 1908), 34–35, however, argues that the work cannot be ascribed to an ancient author at all. He criticizes the author ("dieser konfuse Mensch") and argues, that the paddle-wheel was unknown as a means of transport, because it was not efficient without an effective engine. Therefore the liburna, in his opinion, cannot be an ancient invention and he states, concerning the work, that "nichts darin ist antik, alles mittelalterlich"—Schneider refers in his context also to the proposed reforms of the mint and the army.

[89] Thompson, *Reformer*, 2–6. As for the language of the Anonymus see Thompson, 4–5. He considers him to be familiar with classical authors as Cicero, well versed in the Latin language, acquainted with the chancellery style of official documents but not a skilful stylist. See also Seeck, *Anonymi*, 2325 ("Latin ist sehr unbehülflich"); Baldwin, "The *De rebus bellicis*," 34–39; Ireland, *Rebus Bellicis*, VIII–X. Brandt, *Zeitkritik*, 9–10, also assumes that the author lived the western part of the empire; see for this opinion also Baldwin, "The *De rebus bellicis*," 32–39; Astin, "Observations," 398–401. Seeck, *Anonymi*, 2325, states, however, that the author's "geographischer Gesichtskreis endet an der Donau" and sees him as someone with an oriental background.

[90] Thompson, *Reformer*, 5. Brandt, *Zeitkritik*, 8, argues that the Anonymus was a privatus and that he—because of his critical remarks about members of the upper classes and officials—probably did not belong to this group of people.

[91] Brandt, *Zeitkritik*, 8–9, as well states that he might rather be a pagan; Baldwin, "The *De rebus bellicis*," 32, regards him as "neutral in religious matters."

[92] Meißner, *Fachliteratur*, 106.

[93] Liebeschütz, "Realism," 137.

[94] See Baldwin, "The *De rebus bellicis*," 32–39. He sees him as a "knowledgeable civilian" and "man of some means." Astin, "Observations," 398–401, regards him not as an imperial adviser or a high official, but as a private citizen. He assumes that he had not served as a soldier and has "seen little or no active warfare." As regards his economic situation he assumes that the author possessed "at least moderate wealth and independence" and was maybe "a landowner of curial status."

As for the reception of the work it has been debated whether the emperor ever read it. Thompson doubts this and states: "On the whole it is much more likely that the de rebus bellicis was intercepted by a civil servant and pigeon-holed without ever reaching the Emperor."[95] The fact that the work was copied and transmitted at least indicates that it later attracted a certain amount of interest. As Thompson has convincingly shown the text was transmitted using four different copies made from the Codex Spirensis, compiled in the ninth or early tenth century.[96] With respect to the history of the transmission prior to this time, Thompson supports the view of Seeck that the text itself in the Codex Spirensis was copied from a slightly older manuscript that may have existed at the court of Charlemagne. Thompson further assumes that the different texts—among them the Notitia Dignitatum—gathered in the Codex were already put together at an earlier date.

Concerning the social status of the Anonymus, contrary to Nörr, Brandt argues that he did not belong to the curiales, but he rather sees in him "einen hochrangigen Zivilbeamten."[97] He deduces that in some parts of his works he seems to be critical of the urban elite and takes up the position of the ordinary people. Thompson stresses the fact that the Anonymus is especially concerned with the defense of the frontiers in the East.[98] He concludes that the original corpus might have been put together in the East, i.e., maybe in Constantinople. He even assumes that the Anonymus sent his work to Valens and not to Valentinian.

On the whole Thompson conjectures that the original codex was owned by a Roman official and that the Codex Spirensis was a copy of the original text; the manuscript text of the de rebus bellicis was therefore a copy of the original work sent to the emperor and probably withheld by a court official.[99] The consequences of the theory are substantial. Such a transmission history would imply that there was never an officially published version of the text.

[95] Thompson, *Reformer*, 5–6.

[96] For the manuscript-tradition see Thompson, *Reformer*, 6–17; also Marcellin Berthelot, "Sur le traité *de rebus bellicis* qui accompagne le Notitia Dignitatum dans les manuscripts," *Journal des Savants* (1900): 171–77; Ireland, *Rebus Bellicis*, x–xvi; Schneider, *De Rebus Bellicis*, 25, for the transmission together with the Notitia Dignitatum and the provenance from the imperial archives.

[97] Brandt, *Zeitkritik*, 10.

[98] Thompson, *Reformer*, 14.

[99] Thompson, *Reformer*, 14. He assumes, 15, that the work was never published by the author.

The copying of the work probably started rather late.[100] An important step in the transmission of every ancient text is the first print version. In the case of the de rebus bellicis the first print dates back to the year 1552 and was produced by Gelenius in Basle—including the illustrations—although in a "drastically modernized form."[101] This edition was reprinted several times (1607, 1608, 1623, 1651, 1729, 1908).[102] With respect to the adoption of the ideas of the Anonymus, it has been proven that at the time of the Renaissance, the book was widely read. The scholars were, as Thompson emphazises, "interested in the book primarily for its practical value."[103] An interesting observation is the fact that the first reception of the *De Rebus Bellicis* was not one of the text but rather of the drawings. Obviously the drawings of the manuscript enjoyed an independent tradition.[104] As Thompson points out the drawings of the inventions of the Anonymus were transmitted separately and before the first print—in Italy and in the rest of Europe. As an example he refers to the work of Konrad Kyeser von Eichstädt who, around the end of the fourteenth century, wrote a treatise with the title *Bellifortis*. In this work he discusses the construction of a scythed chariot, which was obviously of particular interest for the engineers of the Middle Ages.[105] As Thompson observes the chariots described by Kyeser are "almost identical" with those machines which were designed by the Anonymus.[106] Kyeser was also interested in a ship and a bridge and, as Thompson notes, he wanted "to bring the Anonymus's ideas up to date and to put them into practice."

The most famous scholar who studied the ancient texts and illustrations was Leonardo da Vinci. So Russo states: "seine Reise war weniger eine fantastische Expedition in die Zukunft als vielmehr ein Eintauchen in ferne Vergangenheiten."[107] Leonardo was in general very interested in the works of

[100] Thompson, *Reformer*, 15: "At any rate, it is clear that before the *de rebus bellicis* was transcribed into the archetype of the Spirensis it had been copied and re-copied a sufficient number of times to allow the text to become deeply corrupted in more than one passage."

[101] See Thompson, *Reformer*, 17.

[102] For the inferiority of the later edition of Reinach see Thompson, *Reformer*, 17–18. For the first print see Ireland, *Rebus Bellicis*, xvii–xxiii; for the print together with the Notitia Dignitatum (by Gelenius 1552 and Pancirolus 1593 and the reprints), see Seeck, *Anonymi*, 2325.

[103] Thompson, *Reformer*, 18.

[104] See Thompson, *Reformer*, 18. See also the respective chapters in Neher and Reinach.

[105] For the chariot see also Thompson, *Reformer*, 54–58.

[106] See also Marcellin Berthelot, "Le livre d'un ingénieur militaire à la fin du XIVe siècle, *Journals des Savants*, (1900): 1–15, 85–94.

[107] Russo, *Revolution*, 384.

the ancient engineers. He clearly also knew the Anonymus de rebus bellicis. Several passages can be considered as evidence. Leonardo for example knew the construction of a bridge designed by the Anonymus.[108] Thompson assumes that Leonardo imitated in some of his inventions constructions of the Anonymus. He supposes that he probably did not know the Codex Spirensis but rather copies of the drawings.

As Russo emphasizes there were other scholars, too, who devoted themselves to the study of authors like Philon of Byzantium and other ancient engineers. He singles out Mariano Taccola, who lived in the fifteenth century and was especially interested in the works of Philon of Byzantium, and Francesco di Giorgio Martini who wrote about architecture, technology and warfare—combining his descriptions with illustrations. Leonardo himself studied the works of Heron of Alexandria and it can be shown that many of his designs are in fact inventions of Heron.[109] The fifteenth century is also the time of the collection and translation of ancient natural scientists.[110] The reception of the work of the Anonymus has therefore to be seen in the context of a general trend. It guaranteed, however, the transmission of the text.

Thompson stresses that the scholars of the Renaissance were first interested in "the Anonymus' practical value."[111] This obviously changed in later times. The work began to be appreciated less. Significant in this context is the attitude of Panciroli who in 1593 refused to work on a new print edition of the work because he thought the technological progress of his own time superior to the inventions of antiquity.[112] As for the reception of the Anonymus in later centuries Thompson states that in the seventeenth and eighteenth centuries the work "fell into that obscurity from which he has never fully emerged."[113] He emphasizes that sometimes scholars still referred to the work but no longer regarded it as being of practical value. Another reason why the

[108] See Thompson, *Reformer*, 19; see also Reinach, *Homme d'Idées*, 241–65. For the reception of the Anonymus in the Middle Ages and by Leonardo see also Henry Hodges, "The Anonymous in the Later Middle Ages," in *De Rebus Bellicis*, ed. Mark W. C. Hassall (Oxford: BAR, 1979), 119–26. See Liebeschütz, "Realism," 136–37, for the reception of ideas by Leonardo (for example, the bridge and the chariot). He doubts, however, that Leonardo "thought of these drawings as practical designs."

[109] See Russo, *Revolution*, 383–84.

[110] Russo, *Revolution*, 383, for example points to an Italian manuscript with the title "machine idrauliche, di guerre" which contained a translation of Philon's work on pneumatics and other works on military technology.

[111] Thompson, *Reformer*, 19.

[112] See Thompson, *Reformer*, 19.

[113] Thompson, *Reformer*, 19.

author was forgotten was the fact that the work is not of high quality literary value. Therefore it did not arouse the interest of the philologists.[114]

As Thompson points out, the renewed interest in the Anonymus began in the middle of the nineteenth century but was confined to machines. The inventions were not, however, taken as serious innovations but rather belittled.[115] As Thompson observes, the work was rediscovered once again after 1918.[116] He points in particular to the studies of Reinach, Piganiol, Neher, Müller, Oehler. The inventions of the Anonymus seemed so advanced to Schneider, that he assumed only a scholar of the fourteenth century could have designed them.[117] The innovations suggested by the Anonymus comprise various aspects of the imperial administration.[118] In the preface he justifies his proposals in connection with the difficult circumstances encountered by the empire.[119] He therefore includes in his work a detailed description of what he regards as the main problems of the administration.[120] Extensive passages deal with economic problems.[121] Combined with this are suggestions pertaining to the reform of

[114] Thompson, *Reformer*, 20.

[115] See Thompson, *Reformer*, 21, referring to the negative judgement of Hermann Köchly, Wilhelm Rüstow, Griechische Kriegsschriftsteller, I (Leipzig: Engelmann, 1853), 414–19.

[116] Thompson, *Reformer*, 21–22.

[117] See Thompson, *Reformer*, 22.

[118] For the proposed reform of the coinage and the mint see Thompson, *Reformer*, 26–31, 34–37. For an administrative reform see Thompson, *Reformer*, 37–41. For the reform of the military see Brandt, *Zeitkritik*, 103–24; for the juridical reform see 125–33 For the financial reform see Brandt, *Zeitkritik*, 11–60. For the reform of the fiscal system and the provincial administration see Brandt, 61–101.

[119] For the content and style of the preface—the address to the emperor, the explanation for the work and the reasons for the plans of reforms see Thompson, *Reformer*, 22–26. As he observes the author takes great caution not to offend the emperors. For the preface and the effort of the Anonymus to justify his reform proposal see Brandt, *Zeitkritik*, 5–8. See there also for the intention of the work.

[120] For the description of the decline of the empire and the analysis of possible reasons see Thompson, *Reformer*, 31–34.

[121] In Brandt's opinion, *Zeitkritik*, 6, the main interest of the Anonymus was a financial and economic reform. He stresses that the Anonymus himself calls the inventions "adnectenda." Brandt states, 8, that the constructions are "von zweitrangiger Bedeutung." Their intention is above all cost saving by reducing the manpower requirements of the military. For an overview over the economic aspect of the work see Frank Kolb, "Eine modernde Imperialismustheorie im Anonymus De rebus bellicis?" in *Miscellanea di studi classici in onore di E. Manni, Bd. IV* (Rome: Bretschneider 1979), 1257–63. Astin, "Observations," 435, states that "the author's fundamental concern and motivation is with pressures of a financial kind or of financial origin upon those whom he regards as the taxpayers of the empire." See also Patsy Vanags, "Taxation and Survival in the Late Fourth Century: The

the military.[122] Among them are descriptions of technical innovations—for example the concept of a new type of ship. The Anonymus stresses that his new inventions will be labor saving.[123] As Thompson points out, in earlier times it was not necessary for the Romans to change the construction of ships due to the "abundance of their slaves."[124] In the times of the Anonymus, however, the promise of labor-saving inventions was regarded as a convincing argument. The relevant passages from his work have already been cited above. Below, the type and construction of the means of transportation developed by the Anonymus will be discussed in further detail. In principle, the mechanism the Anonymus used for the propulsion of the paddle wheels was not new.[125] As shown above it was widely used for the driving of mills. The question is how the Anonymus came up with the idea to connect the wheels to a ship. A device that is described by Vitruvius has been suggested as a possible model.[126] It involves a contraception which was attached to the side of a ship to measure distances traveled. Thompson, however, regards it as improbable that the Anonymus took this construction as his pattern.[127] He assumes that his construction was a combination of the mill powered by animals and the undershot vertical water mill. He also suggests that the Anonymus may have been inspired by water mills con-

Anonymus' Programme of Economic Reforms," in *De Rebus Bellicis*, ed. Mark W. C. Hassall (Oxford: BAR, 1979), 47–57.

[122] For the reform of the payment of the army—that is a reduction of the expenses for the military see Thompson, *Reformer*, 41–44.

[123] Liebeschütz, "Realism," 135, stresses the novelty of the concept that an invention could be labor saving and so help to save money. The Anonymus explicitly and repeatedly states his inventions, i.e., his innovations will be labor saving. See Thompson, *Reformer*, 49. "he gives us beyond doubt the immediate reason for his inventions: they are designed to save manpower in the army." Humphrey, Oleson, and Sherwood, *Technology*, 34, more specifically assumes that the proposal was "stimulated by a shortage of trained oarsmen." For the aspect of economic reform and labor-saving measures see Meißner, *Fachliteratur*, 106–7; for the question of manpower shortage see Astin, "Observations," 401–5. In Astin's opinion, 408, the liburna was not designed for "substituting animal power for scarce human power" but to achieve maximum speed. That this could be achieved without manpower is according to him emphasized by the author because "he has envisaged a ship of such vastness and speed that it could not be powered manually."

[124] Thompson, *Reformer*, 51–52.

[125] Wikander, *Industrial Applications*, 409, stresses, that the liburna presupposes knowledge of the use of water power. He also sees a possible connection with the floating mill.

[126] Vitruvius, *De Architectura*, X, 9, 5ff. See Wilson, *Machines*, 358, for the Hodometer, described in Vitruvius, *De Architectura*, 10, 9 and 11; for the Hodometer see also Aage G. Drachmann, *The Mechanical Technology of Greek and Roman Antiquity* (Copenhagen: Lubrecht and Cramer, 1961), 159–61.

[127] Thompson, *Reformer*, 50.

nected with boats like the ones employed by Belisarius.[128] This would naturally imply, that these technologies were already known and familiar in his time.[129]

The question of the origin of the new concept of a ship cannot be answered with certainty. Another point is, of course, why the Anonymus developed his ideas in this specific period. An important reason for the introduction of new technologies was probably a decrease in the numbers of slaves and therefore the available workforce.[130] The Anonymus appears to have been interested in the consequences this would have had on the defense of the Empire. In this context he also develops possible improvements for the Roman fleet.[131] The improvements which were proposed by the Anonymus were never put into practice, at least not on a larger scale. This again leads to the question why everything that was possible was not implemented?[132] Thompson sees the reason for the failure of the Anonymus in the fact that he was "an isolated phenomenon" and unique. Another factor which prevented the application of the inventions was in his opinion the structures of society.[133] Thompson points to the fact that the Anonymus himself refers to the fact (Preface 4) that members of the upper classes did not occupy themselves with technical progress.[134]

[128] Thompson, *Reformer*, 51, points to the fact that the water mill was used more widely in the time of the Anonymus; he states that "if he had lived fifty years earlier it is unlikely that the idea would have occurred to him." He assumes that the author was inspired by the sight of a water mill and stresses that the liburna was designed in "the overlapping period when both types of mill were in comparatively common use, and the new mill had not yet ousted the old one." Forbes, *Studies*, 105, also sees a connection between the paddle wheeler and the concept of the water mill, stating that the liburna was utilizing the inverted principle.

[129] Thompson, *Reformer*, 51, emphasizes that "we have no proof that Belisarius' idea was an original one" but stresses that Procopius was obviously impressed by the novelty of the invention. Wikander, *Use*, 100–101, however, regards the connection between the floating mills and the paddle wheeler as uncertain.

[130] See Thompson, *Reformer*, 47.

[131] See Thompson, *Reformer*, 52, for the deficiencies of the Roman fleet in this time. For his other inventions see Thompson, 54–69.

[132] For the question why for example the steam engine was not used—although being developed in principle by Heron—see White, *Technology*, 195.

[133] Thompson, *Reformer*, 81–82.

[134] Thompson, *Reformer*, 44. As Thompson points out, 44–45, this did not change in the time of the Christian empire because "for Christians of the upper classes scientific research was, at best, of little interest and less importance. At worst, it was blasphemy." (Thompson here refers to the opinions of church fathers). In his view those who were responsible for the few advances in the field of scientific research were not members of the upper classes. Thompson especially point to the comparison the Anonymus draws between the negligence of the Roman upper classes and the interest of barbarian tribes in technological advancement (referring to

An important aspect was of course the possibility to realize the concept of the ship. With respect to the liburna, Thompson stresses that the construction of such a ship was possible although its value in battle may be doubtful.[135] A similar view is presented by Hassall.[136] Wikander states that there is "no actual reason, why the construction should not function."[137] Schneider regards the inventions as "meist ganz unbrauchbare Dinger und voller Unsinn, andere sehr primitive Einrichtungen, die nur bei einem Ignoranten Staunen und Bewunderung hervorrufen konnten" and judges the liburna as "geradezu verrückt."[138] Several authors have taken the view that the work of the Anonymus is nonscientific.[139] Thompson stresses that the Anonymus made his inventions "on paper only" and did not build models of his constructions.[140] He sees here the already mentioned technophobic influence of the attitude of the upper classes. This contempt of manual labor is in his opinion also responsible for the fact that he has no doubts concerning the practicability of his constructions.[141]

A knowledge of ancient technology was not lost in the Middle Ages.[142] Ancient manuscripts were transmitted and ancient technologies adapted

passages in Procopius and Zosimos). For the attitude toward manual labor see also Humphrey, Oleson, and Sherwood, *Technology*, 580–99.

[135] For the practicability of the inventions (which were obviously never built) see Thompson, *Reformer*, 78–79; Liebeschütz, "Realism," 136, states that the mechanism could not have been powered by oxen, because they would have been too slow.

[136] Mark Hassall, "The Inventions," in *De Rebus Bellicis*, ed. Mark W. C. Hassall (Oxford: BAR, 1979), 77–91.

[137] Wikander, *Use*, 100–101. For the construction of the ship see Landels, *Engineering*, 15–16 (including a reconstruction). He sees "no theoretical reason why this should not work," but judges that "the whole idea does not sound very practical."

[138] Schneider, *De Rebus Bellicis*, 33.

[139] See Forbes, *Studies*, 102–3. Liebeschütz, "Realism," 125–32, emphazises the novelty of the inventions, but criticizes that the illustrations and explications are insufficient. Astin, "Observations," 436, regards it in general as "extremely unlikely" that the reform proposals of the Anonymus "had any discernible effect, or indeed any effect whatsoever on the practices of the Roman empire."

[140] Thompson, *Reformer*, 77–78. Brandt, *Zeitkritik*, 9, states that the Anonymus probably had little practical experience concerning military affairs. For a comparison with Vegetius see Brandt, *Zeitkritik*, 150–54.; Thompson, *Reformer*, 79.

[141] For his attitudes toward the different social classes and a comparison with the deliberations of Salvian see Thompson, *Reformer*, 85–89.

[142] Of course many texts were lost—especially the works of the scientists of the Hellenistic Age. See Russo, *Revolution*, 7–12; see Forbes, *Studies*, 106–8, for a passage in Venantius Fortunatus, *Carmina*, III, 12, 37f. (dating to around 600 AD). See Oleson, *Devices*, illustration no. 169, for the tread-wheel-driven chain-pump, designed by Gregorius Agricola, *De re metallica*, 1556.

and improved. The use of the waterwheel as an engine was of course widespread in medieval times.[143] There are, however, only a few examples for the attachment of wheels to a ship—or at least of the powering of boats by waterwheels. In the fourteenth century a certain Taccola designed a boat with waterwheels which was secured by a rope to a point upstream. Through the impact of the water the wheels were set in motion and the boat was pulled upstream.[144]

Yet there are many references and depictions of the so-called boat mills.[145] The earliest known examples of such mechanisms were the devices built in Rome in the first half of the sixth century. Since then, boat mills have been mentioned by a number of authors.[146] There are also depictions of these boat mills in various manuscripts.[147] A further development during the Middle Ages and early modern times was the bridge mill, that is the attachment of waterwheels to bridges.[148] Water mills were common from the Middle Ages onward.[149] In modern times the waterwheel was also used in the context of industrial production.

The idea of setting ships in motion by a new propulsive power, however, persisted in medieval times.[150] As already mentioned, ancient technology was adopted on a larger scale at the time of the Renaissance. The work of the Anonymus, however, did not enjoy the same acknowledgment in the following centuries. It was rather the ingenuity of Leonardo that was emphazised.

[143] Reynolds, *Water Wheel*, 47–121. For the use of waterwheels in medieval times, see also Forbes, *Studies*, 49–64; Cardwell, *Wheels*, 49.

[144] See Reynolds, *Water Wheel*, 79 and 81.

[145] For the types of boat mills see Reynolds, *Water Wheel*, 56–62; Wilson, *Machines*, 357.

[146] See Reynolds, *Water Wheel*, 56–69, who adduces Marius, bishop of Avenches, the Chronicles of Martin of Trier, Albertus Aquensis.

[147] See Reynolds, *Water Wheel*, 56–57 (pointing to the "Mills of Babylon" depicted in a French manuscript dating to the fourteenth century). Forbes, *Studies*, 106, sees the depiction of these mills as a referral to experiences of the crusaders. For the number of boat mills in Paris see Reynolds, 57—with additional references.

[148] See Reynolds, *Water Wheel*, 58–69 Forbes, *Studies*, 106, for mills for example under bridges over the Seine, the Garonne, the Loire, and other rivers. See Forbes, *Studies*, 106, also for the floating paper mills near Bagdad and the boat-mills near Venice; see Wikander, "Sources," 143–44, for the floating mill.

[149] Wikander, "The Water-Mill," 398–400, for the use of mills in the time of Late Antiquity and the Middle Ages. See also Forbes, *Studies*, 106–15, for the increasing importance of watermills in these periods and the progressive specialization.

[150] Russo, *Revolution*, 158–59, referring particularly to the remarks of Roger Bacon, *Epistola de secretis operibus*, IV.

Modern assessments of the inventions of the Anonymus vary. There are scholars, as for example Seeck, who belittle the work as the "Denkschrift eines verrückten Projecktenmachers."[151] Liebeschütz questions the seriousness of the whole proposals.[152] But Liebeschütz also judges the concept as sound and assumes that it influenced the later development of the paddle wheeler.[153] Thompson goes further and points out that from the time of the Renaissance onward, "when the needs of the new bourgeoisie of many maritime cities of Europe demanded improved ships, the Anonymus's suggestions attracted considerable attention." He makes a connection between this and the emergence of paddle wheelers in the seventeenth and eighteenth centuries.[154] Even if a direct influence cannot be proven, the Anonymus's ideas were at the very least original and innovative.[155]

[151] Seeck, *Anonymi*, 2325; see the similar judgement of Schneider, *De Rebus Bellicis*, 26–43.

[152] Liebeschütz, "Realism," 132, characterizes the inventions as "not for the reader to build or use, but for him to marvel at." He further, 134–35, assumes that the work of the Anonymus was in fact "his own playful version of the programme being publicized on behalf of the emperor by the philosopher Themistius."

[153] See Liebeschütz, "Realism," 136—he points to the "Castle of Delft," an early model of a paddle wheeler from Holland, and a ship powered by horses which belonged to Prince Rupert and dates to the second half of the seventeenth century. See also Hassall, *Inventions*, 87.

As regards the inventions of the Anonymus Liebeschütz, "Realism," 136, states that they show "striking imagination" but that due to the technology of his period they could not be realized. The concept of the paddle wheeler is in his opinion "brilliant." He stresses, however, that "the idea...is also something of a joke."

[154] Thompson, *Reformer*, 52: "The entire process was inspired directly in the earlier centuries and indirectly in the later by the drawings of the Anonymus."

[155] For the question of the originality of the author see Brandt, *Zeitkritik*, 163–65, who speaks of a "naiven, personalisierenden Geschichtsauffassung" and warns that the work should "nicht überschätzt werden." For the question of the originality of the Anonymus see Thompson, *Reformer*, 75–82. He assumes, based among others on the fact that "his proposals are based so closely on the techniques of his own day" and address difficulties and problems of the fourth century, that the inventions described by the Anonymus were largely his own and that the fact that he sometimes characterizes them as already ancient and tested machines has to be seen as a purely literary device by which he wanted to convince the emperor. See the differing opinion of Brandt, 155–65. See also Astin, "Observations," 399–401; Liebeschütz, "Realism," 134, who considers the work as "new and original."