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The Forerunners of Standardization

The use of standards to aid in the progress of humans, and even other species, dates back to the dawn of time. The storage, duplication and transmission of genetic material leads to the reproduction of similar beings, standard individuals adapted so that a species might survive the competitive processes of evolution. Beyond this primordial genetic stage, among evolved species, epigenetics allowed a species to pass on standard know-how and knowledge (feeding yourself, protecting yourself and so on) to their descendants and other similar beings to increase their chances of survival and promote the well-being of those communities. This holds true for the species *Homo*; however, it is not the only species passing on information – consider nests, termite mounds, beehives, corals and beaver dams. However, the long line of hominids is certainly the line of species that has produced the highest number of tools or made the most modifications to the environment. The use of language by *Homo sapiens* allowed technology to spread far and wide. The basis of each language is the *lexicon*, which allows users to understand categories of beings, objects or events that are considered to be *standard*. All societies require norms, in the broadest sense of the term. Complex societies, with highly specialized tasks, must quickly distinguish between norms practiced by the community as a whole and *standards* that apply to specific sections of that society: these are technical standards[1].

1 Within politically organized societies, there emerges the requirement to share certain norms not only within the nation (or a league of nations), but on a more global scale, as peaceful trade is set up.

It must be emphasized that language, followed by writing, is not the only means of transmitting knowledge and techniques, but it becomes the primary support for performative recording of these standards. Numbers and calculations are simply a subset of writing and significantly prefigure writing. At the same time, numbers govern the normative formalization of weights and measurements[2] especially and are an essential feature of a sovereign power. The discovery and subsequent cultural codification of the technical drawing were also a fundamental dimension of the power of standardization. The architectural forms of a city, the designs and purposes that formalized mechanical techniques used by artisans or in war machines – these are all modes of transmission of technical standards. This chapter presents a few forerunners of modern standardization, pre-dating the contemporary period. For this, 1776 is a convenient marker for Americans[3], a well-known date and effectively approaching the end of the pre-industrial age, which had a wealth of early standardization methods.

1.1. Standardization in Antiquity: writing, knowledge and metrology

The Greek alphabet was one of the earliest normative bases of Western civilization (and, of course, of the Greek world initially). It was the reason it transformed into a society that invented another way of thinking and of transmitting science as distinct from technology. There have been many commentaries on the influence of writing, through technical progress in producing writing, the supports used, and in printing. Despite being the subject of much criticism, Havelock's theory regarding the fundamental contribution of the Greek alphabet to the creation of the *Greek miracle*, resulting in the globalizing transformation of Western civilization, is a perfect description of this key point in standardization in Western cultures (Havelock 1981). It does not matter whether it was really the Greeks who invented the very first alphabet. What is certain is that they were able to standardize a short writing code, which was capable of recording (capturing) speech completely and which was easy to learn and, therefore, easy to share widely. This produced a new cultural ecosystem, both communicational and political, which had never existed before.

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2 Closely linked to proto-coins and then coins.

3 The French Revolution – 1789 – is a similarly striking date for European historians.

Writing, money, networks: inventions of Antiquity, inventions of modernity

Based on concrete evidence from digs, Clarisse Herrenschmidt, an archaeologist and a fine linguist, demonstrated the continuum between proto-writing and the practice of exchanges (whether monetary, linguistic or informatic) within networks:

> Like the *bulla or cylinder seals*, on to which a seal was printed, whether an Eastern seal representing the sender's signature, or a Lydian or Ionian seal indicating the authority issuing the stamp, the packet carried its own identification: the IP address of the machine that issued it (I am ignoring data encryption for the time being). What remains are the geographic and cultural aspects. The stamp seal circulated between Uruk and Syria, between Suse and the Iranian plateau, while the cylinder seal circulated between the Lydian empire of Sardis and Ionian cities. These signs were created to circulate over more or less vast expanses, politically heterogenous in any case. From the start, these packets traveled around the world: this was the true birth of the Web: exchanges between CERN physicists and their colleagues across the Atlantic. The people who exchanged stamps seals and cylinder seals, those who exchanged the packets, may not have spoken the same language, but they certainly shared a code: dice in the old Eastern world, weighted precious metal and a complete alphabet in the Asia Minor of the 7th century BCE, international English and the interconnection protocols and standards used for computers in the late 20th century CE. These writings built upon one another. An arithmetic writing was deployed through the means of money that was minted based on the complete alphabet; writing computer code uses linguistic and arithmetic writing, and contributions from the industrial development of writing, including information technology and the telephone: writing code starts with the premise that languages, beings, the world itself can all be written using numbers. (Herrenschmidt 1999, p. 63)

Box 1.1. *Money, the forerunner of writing and digital networks*

Within this new ecosystem, it became possible to discuss and argue each new proposition of a dialogue and, above all, it was easy to record these debates in writing. A new skill thus emerged, which was no longer simply the *summation of technical discussion* but a perennial process of recording speech, which would form the basis of agreement between experts (artisans, philosophers, savants, traders or buyers). And so began discourse on *technology*[4], which was distinct from *science*. Using these new social competencies and by theorizing on the universe itself, everything seemed possible to the Greeks: questioning their own mythology by distinguishing the physical from the metaphysical, or questioning politics by distinguishing between tyranny and democracy, which, of course, was also their creation. Language itself became a science with the study of grammar, measuring the world through geometry, the essence of knowledge with logic, and, through rigorous association of arguments, it became a means to test the veracity of a proposition.

Disparities in writing culture between Ancient Chinese and Greco-Roman civilizations

Two writing cultures, two cultures that transmitted knowledge and know-how, and two kinds of social and institutional organization for technoscientific governance existed contemporaneously, without any real contact, at the Western and Eastern ends of Eurasia. It is clear that norms around writing, produced by tens of generations of speakers, readers and writers, do not lead to the same social institutions (democracy vs. bureaucracy and empire) nor the same modalities of differentiating (or not differentiating) between technology and abstract science. This leads to specificities in the diffusion of technical knowledge and, therefore, in the modes of standardizing this knowledge. Within both these writing regions, technology did not evolve in the same way over the next thousand years: it was the ideographic world that had the initial advantage. They produced woodblock printing, resulting in text and images that could be widely shared. It was partly thanks to these early books that China could so widely propagate the sophisticated technologies that they had already used for centuries: metallurgy, hydraulics and multi-tube seed drills, for example. As a result of this, these two different writing cultures had different cultural, social and technological futures[5].

Box 1.2. *Other writing families, other technological and social cultures*

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4 From later Greek *tekhnologia*: literally *discourse on techniques* (see Hudrisier 1999, pp. 54–56).

5 For a long time, in Egypt, Mesopotamia, the Indian subcontinent and China, writing was almost entirely an exclusive profession practiced by scribes.

Other populations around the world had asked similar questions, but thanks to the alliance formed between the Greeks[6] and their Roman conquerors, a brilliant civilization emerged that first the Renaissance and then the Enlightenment, rediscovered, amplified and reactivated, and which even today serves as the foundation of European civilization, resulting in the globalized industrial civilization that continues today.

It was thanks to the significant spread of writing among the ordinary people that Athens, and then Rome, could establish standards for weights, measurements and coinage. They also standardized certain sensitive activities that were of importance to the State and its citizens: architecture, urbanism, maritime activities (especially military ones), as well as innovations that had to be preserved through the granting of privileges: creating monopolies[7].

Constructing a town is a fundamental competence among evolved, sedentary civilizations. Aristotle defined this as the fundamental philosophical requirement: “Poiesis is the disposition to produce accompanied by rules” (Aristotle 1997). Three centuries later, in Rome, Vitruvius penned a series of texts not only on architecture but a variety of technical subjects. Vitruvius was a mechanical engineer as well as a military and then civil engineer who served under Caesar during the Gallic wars, and through his *Ten Books on Architecture,* he brought together the processes of engineering sciences in a single book. Like Archimedes and Pythagoras before him, he established a close link between theory and practice: “Architecture is a science that embraces a wide variety of study and knowledge; it knows and judges everything produced by the other arts. It is the fruit of practice and of theory” (Vitruvius 1914). In doing this, Vitruvius was a *standardizer* in the modern sense of this term. He defined a good

6 It must also be highlighted that, to pay homage to the primacy of Greek as well as for international equity, the abbreviation ISO is no longer officially a reference to the International Standard Organization but to the ancient Greek ἴσος, *isos*. This allows the organization to sidestep the thorny question of promoting English over French or Russian (these being its three official languages). Thus, officially, the abbreviation is no longer the abbreviation of the English name (International Organization for Standardization), the French name (Organisation internationale de normalisation) or the Russian name (Международная организация по стандартизации).

7 Etymologically *monos* = single and *polein* = to sell.

architect not only as one who could choose from a catalogue of *styles*[8] that which was best suited for use with the structure, but also a person who could propose rules (*norma*) and was able to reason between theory and practice.

In the Greco-Roman world, we encounter norms in multiple domains: rhetoric, poetic meter, metrology, military and maritime organization and so on. The fact that the *Pax Romana* lasted five centuries was not purely chance. The Romans, of the Republic and then the Empire, were able to establish solid institutions. They had the wisdom to bring about *religious syncretism*[9] and, above all, they put in place a normative framework for exchange: land and sea routes that were well-maintained and under military protection, Greek and Latin (or rather koine[10]) as the bridge language, as well as unified weights, measurements and coinage, which simplified business and allowed trade to prosper:

> Ancient Greece considered the question of monopolies to protect innovations very early on. The oldest known mention is derogatory. It concerns the Greek colony in Sybaris, in Southern Italy, in the 6th century BCE. Athenaeus of Naucratis wrote to Rome in 228 CE in his magnum opus *Deipnosophistae* (Scholars at the Dinner Table): "If a cook among them were to invent a new, very delicate dish, no cook other than the inventor would be permitted to prepare this for one year, so that each of them may try to surpass the other by making similar discoveries." [Later, Aristotle] "complained multiple times about the practice in certain nation-States of conferring monopolies. (Lapointe 2000)

In fact, legal historians consider that the attribution of *privileges* or *monopolies*, awarded on a case-by-case basis, was in existence well before the emergence of any laws on patents[11]. We can, however, highlight this mode of having an innovation acknowledged by governments. While distinct from the question of technical standardization, monopolies and then patents, like norms, are a means for States to govern technologies. This is thus a

8 *Stŷlos*, στῦλος = column. A distinctive feature of Doric, Ionic and Corinthian styles.

9 They were able to establish, through consensus, an interoperability of pantheons, not only between Greek and Roman religion, but also Egyptian and Mesopotamian religions.

10 A standardized linguistic form of the various spoken Greeks, based on an Attic dialect, to facilitate exchanges.

11 Which was legally formalized in Europe, notably in Venice in 1474 and Great Britain in 1624.

subject that is very closely related and complementary to questions of standardization, which we only briefly mention.

The Roman system of weights and measures is particularly interesting, having endured over the centuries, across the expanse of the Empire. *Measurement standards* were submitted to the Capitol as well as other cities in the Empire. Additionally, the principal routes were marked by *milestones*, which were an omnipresent metrological reference, and any number of archaeological traces of these remain.

This system formalized a subtle division of units into multiples and sub-multiples, sometimes in a decimal base, sometimes founded on other numerical systems[12] depending on the professional use. This desire to adapt measurement norms to a variety of practices (social, professional or scholarly) can be seen in all civilizations that developed a system of measurements, a calendar and symbols for trade exchanges. Thus, Babylonian astronomers developed systems for calculating and measuring angles that were much more sophisticated than systems to count livestock or measure grains, which were developed in the same civilization at the same time.

However, in Rome, metrological norms were institutionalized and imposed uniformly across the Empire, whether it was to measure length, area, or volume[13]. The units, as well as their multiples and sub-multiples, were organized according to scales that were adapted to metrological requirements as well as the understanding and capabilities of the users.

All units of measurement were based on two or three numerical bases, sometimes more. Let us look at the example of units of length. These were initially structured based on corporal comparisons, which was practical for daily commerce: threads, fabric, wood. The base unit, the standard for which was submitted to the Capitol, close to the Forum, was the *pes* (foot, or 0.29 m). Its sub-multiples included the *palmus* (palm, 0.074 m) and *digitus* (finger, 0.018 m). Its multiples were sometimes organized across several numerical bases in order to allow the addition of different units to arrive at an exact measurement for some common objects:

– *palmipes* = 1 foot + 1 palm = 20 thumbs = 0.37 m;

12 Decimal, duodecimal, hexadecimal or sexagesimal for angular and hourly measures.

13 Or measuring the capacities for liquids or granular materials.

– *cubitus* or *ulna* (elbow or ell[14]) = 1 foot + 2 palms = 24 thumbs = 0.44 m;

– *gradus* (degree) = 2 feet + 2 palms = 0.74 m.

Depending on the profession, the scales of magnitude and the units would vary. For land surveyors, calculations were essential and the decimal base prevailed[15]:

– *gradus* (single step) = 2.5 feet = 0.741 m;

– *passus* (double step[16]) = 5 feet = 1.482 m;

– *pertica* (perch) = 10 feet = 2.964 m.

On a larger scale:

– *actus* (track) = 120 feet = 35.56 m;

– *stadium* (stade[17]) = 625 feet = 185.25 m;

– *milliarium* (Roman mile) = 5,000 feet = 1,482 m;

– *leuga* (Roman league[18]) = 7,500 feet = 2,223 m.

The assessment of areas, called quadrature, required more complex computations. The base unit was the *quadratus pes* (square foot = 875 cm²). The most common multiples included:

– *decempeda quadrata* or *scripulum* = 100 square feet = 8.75 m²;

– the rectangular metrological unit, the *jugerum*, met the needs of laborers and wine-growers, focusing on units of measurement that were adapted to rectangular plots and were easier to use. Thus, the *jugerum* or the

14 It must be noted that the *elbow*, divided into 24 *thumbs*, was the ideal measurement to assess objects using your own body. It corresponded to the distance between the tips of the fingers and the tip of the elbow. A textile merchant could combine the action of unwinding a bobbin or roll of cloth with the act of measurement using nothing but their arm.

15 In Latin, as in many other languages, the lexicon of numbers is primarily a decimal one. However, while ill-suited to commercial exchanges, this decimal base is essential for calculations using an abacus.

16 The *double step* and *perch* were useful in measuring the dimensions of a room.

17 The *arpent* and *stade* were used for agricultural measurements.

18 The *mile* and *league* made it possible to calculate distances between cities. A *Roman league* was the distance that could be covered on foot in around 30 min.

track was an area of 240 feet multiplied by 120 feet, or 28,800 square feet, approximately 2,520 m^2.

On a more complex metrological scale, land records or assessing the area over which an Empire extends, geometricians and astronomers turned to geodesic techniques involving angular measurements to assess areas across vast territories. This operation, known as centuriation (*centuratio*), was distinct from localized land surveying. Based on limits or high points, they would triangulate and map large regions[19].

Monetary units are a particular case in point: there were large variations in the value and metallic and alloy composition of the *as*, *sesterce, denier* and the *aurei* between the third century BCE and the end of the Western Roman Empire. While devaluation allowed the authorities to write off State debts, the names of the coins as well as their relative hierarchy remained unchanged in order to preserve fiduciary value[20].

After the fall of the Roman Empire, Charlemagne tried to retain the universality of Roman weights and measurements. While the names for the units survived in Europe until the advent of the metric system, universal metrology was lost. A monumental statue of Roland of Roncevaux still stands in Bremen (a former Hanseatic town): the distance between the pointed knee guards of his armor served as the standard measure for the *Bremen ell*.

This precious heritage of Roman metrology was preserved in England alone, thanks to William the Conqueror and, as we will see, this benefitted the British Empire and the United States.

1.2. The stages of the standardization of text before printing

From *poetic meter* to digital publishing, over millennia all civilizations have innovated in order to standardize, record and pass on the *word*. The terms themselves testify to this: the *Iliad* and the *Odyssey* were composed in *dactylic hexameter*[21]. As in many cultures, it was thanks to the *meter* (or,

19 See Decramer (2002, pp. 137–150). Spatial technologies have replaced these skills.

20 A value in which we trust (*fides* = faith). Master weights as well as a minting workshop were found in the temple of Juno, overlooking the Forum in Rome.

21 In Greek: ἕξ (*héx*) = six and μέτρον (*métron*) = measurement.

more broadly, *poetic meter* and *musical rhythm*) that oral literatures were passed on and preserved. The appearance of the book was a fundamental stage, especially the emergence of the *codex*, which progressively replaced the *volumen* (a book in scroll form), from the first century CE onwards. Printing marked a major transformation and, even today, we are far from comprehending the full impact of the digitization of books and writing.

In the Greco-Roman world, authors, who were generally from the patrician class, dictated their works[22] to scribes (often slaves or freedmen) whose responsibility it was to transcribe this work. From the first century CE, Rome saw the emergence of a true Republic of Letters. Authors organized public lectures and exchanged corrections. A number of successful books had circulation figures that are comparable to figures from our own times (between 1,000 and 2,000 copies), traveling to the ends of the Empire. The first ancient form of a book was the papyrus scroll, which imposed a sequential reading of the text. However, the *intelligent reader* (one who was adept at *inter-legere* or “reading between the lines”) was not satisfied with closely perusing two or three[23]. To deepen their understanding, they would spread out armfuls of volumen across their table, thereby creating folds, enabling them to *ex-plicare* (*unfold*), that is, understand something hidden within the folds of the text[24].

The emergence of the codex in the first century CE marked a significant cognitive revolution (Goody 1979). This form freed the reader from the necessity of reading sequentially and allowed them to gain a more global understanding of the text. When reading a scroll, in order to follow the thread of a discourse, the text had to be tagged systematically[25] (in the Gospel, for example[26]: John, book 4, verse 48). The codex simplified reading, thanks to a table of contents and systematic numbering of pages,

22 With a few exceptions, this practice continued until the Renaissance.

23 In Latin, *pagina* is both the *page in a book* and *plots in vineyards.* The analogy becomes clear when you imagine several columns of text juxtaposed in a section of a scroll, like well-aligned rectangular plots in a vineyard.

24 *Lire à Rome* (Reading in Rome) (Salles 1992) as well as *Rome : l’esprit des lettres* (Rome: The Spirit of Writing) (Porte 1993) are two fundamental books, from which we have taken most of the information given here.

25 This prefigured XML tagging of texts, which became essential because of their undifferentiated digital form.

26 This was the same across all books in scroll form, especially the books of the Quran and Torah.

which rendered these tags useless. Thus, the reader benefitted from a panoptic view of the text, allowing easier understanding and a more flexible manner of reading. A notable fact is that the codex was first adopted for technical, scientific and historical texts and its use for literary, religious and poetic texts was much slower.

From the High Medieval period, Charlemagne, with the help of his Palatine Academy, especially Alcuin, embarked upon the project of a normative overhauling of how reading and writing were taught. He standardized new codes, especially punctuation:

> With the new *Carolingian minuscule*[27], the beginning of sentences could easily be identified thanks to the initial majuscule of the first word. There also emerged punctuation marks similar to musical notations […] However, the concept of the word still remained unclear […] In the 12th century, the words were clearly individualized and, when the copyist had to split a word at the end of a line, he would insert a hyphen. Punctuation, both within sentences as well as at the end of the text, was indicated by a point. (BnF n.d.a)

At the end of the Medieval period, the progressive standardization of books marked a turning point. Formatting was codified in order to meet the needs of exchanges of manuscripts between clerks in the Christian world: a central reference text, flanked by drop case letters, rubrics, explanatory areas of text framing the main text, as well as marginal notes and illumination. These typographic standards catered to specific uses of these texts: reading to monastic assemblies, *readers-commentators-authors* working in libraries, or again, monks meditating in their cells upon the writings of leading Doctors of the Church. There was a spectacular growth in the market for handwritten books: between the 10th and 12th century, demand doubled and then tripled. It was in this period, the late Medieval period, that the technological and economic balance around books was overturned. As books went beyond the conventual context, which had been strictly regulated thus far, the secular production of manuscripts also required *standards approved by institutions*.

27 From the Latin name for Charlemagne: *Carolus Magnus*.

1.3. The *pecia:* de jure standardization of a manuscript

The *pecia* is a term that is relatively unknown outside of specialists who study manuscripts. However, thanks to this system, the handwritten book saw considerable growth three centuries before the invention of printing. This was the time that the earliest universities were founded, such as the university of Bologna (1088–1158) and the Sorbonne (1200–1215). These new intellectual centers generated an increasing demand for books, which began to be published in the proper sense of the term. This production was carried out under the strict and normative control of the university. Contrary to what one may think, paper (which was widely used in Europe a century before printing) was not the material used for the handwritten copies of the books. In fact, the quality of these early papers was poorly suited to writing and made it practically impossible to strike through a word. Furthermore, the material was fragile. Thus, parchment remained the best suited material to produce these handwritten manuscripts.

In Latin, *pecia* means "a piece" (in this context, *a piece of* skin, generally mutton). By extension, therefore, it referred to a fragment of parchment (folded *in folio* to form four pages, or *in quarto* for eight pages) on which the copyist would write. To guarantee that the copies remained faithful to the reference manuscript, usually held by the university, the *stationer*[28] had to first have invested in *exemplaria*[29], the copy of which had to have been certified as a true copy of the original. Each *exemplar* was made up of tens of *pecia*, each of which contained four to eight folios that could be simultaneously copied by several copyists. The stationer would rent their *peciae*, generally for a week, which was the time taken by a copyist to make a copy. If there was high demand and the *pecia* had been rented many times, this meant that the book was selling well, thus allowing the stationer to recover their initial investment. Stationers thus became *accomplices of the university*: both entrepreneurs and guarantors of handwritten publishing, they ensured that academic production was standardized and certified. Each university's *commission for petitions*[30] exerted strict control over the entire process: they ensured texts conformed to the reference, the prices being

28 Publisher-bookseller, giving us the term "stationery" today.

29 One *exemplar*, many *exemplaria*.

30 *Petitioners*, in the older sense of "representatives of authority".

charged for the texts were fair and that the production standards were rigorous. All these requirements were precisely defined in detailed rules[31].

1.4. Printing and engraving: tools of standardization

Before 1500, printers of *incanubles* (the very first printed books) had to mimic medieval manuscripts. They were printed on vellum, the only material made of skin that was suited for printing, and the first fonts sought to reproduce Gothic handwriting, which was then in vogue. However, this soon brought up many problems that were almost insurmountable.

For the typographic composition of his 42-line Bible (1452–1455), Gutenberg had to have more than 290 different characters: initial letters, median letters, final letters, and isolated letters, not to forget ligatures and other characters that connected letters to each other (Wild 1995). This process made it possible to mimic handwritten manuscripts; however, it quite significantly complicated the printing process and increased costs. Despite this, 180 copies of the first book were made.

Starting from the second edition, called the 36-line Gutenberg Bible (1461), close to a hundred characters disappeared from the first typeset case. Typographic standardization had begun. From 1500 onwards, and within a few decades, the typeset case stabilized to carry around 100 types, divided into four sections[32].

There were precursors to typography standardization. Printers such as Nicolas Jenson (1420–1480), established in Venice, participated in this by engraving the Roman-style letters (in contrast to Alde Manuce's italics) to mimic handwriting. This evolution resulted in a fundamental technical and cultural transformation: the radical split between the printed text and handwritten text.

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31 For more information on the concept of *pecia*, an important source is the article by its modern re-discoverer, Jean Destrez (1923).

32 A typeset case or type case was a wooden box divided into compartments. Each compartment would contain different typographic letters. A specific drawer or case for capital letters was fitted above the case holding the other letters, leading to the terms "uppercase letters" and "lowercase letters", which are used even today.

Font production was quickly industrialized. Permanently engraved steel printing punches could be used to create a large number of copper molds ("matrices") for different characters. This allowed smelters to produced re-usable letters made of lead. From the 16th century onwards, certain European states published the first royal technical standards to ensure that the collections of lead types with different printers would be interoperable, compatible with each other, and long lasting. These decrees defined certain font measurements, the height of the characters and the typography point.

In the early decades of the 16th century, bookstore catalogues expanded considerably: technical volumes, scholarly works and, of course, secular literature.

For a manuscript to be copied, the parchment had to be smooth so that the quill would not snag on the fibers. On the other hand, printing a sheet (which would then be folded to create a "quire" of 4–8 pages) required an absorbent material. Paper that could not be used for handwritten documents was easier to produce and, fortuitously, it replaced parchment. Printers developed oil-based inks which had longer drying times but were easier to print on to paper. The techniques of arranging pages over one large sheet that would then be folded to form quires followed the same principles as those used for a *pecia*.

The format of the codex remained almost unchanged from the 1st century to the 21st century. There have only been marginal changes in technical details: the material (papyrus, parchment, paper) and the binding (quire stitched together, or glued together to be cut by the reader). The formats depended on the number of times the sheet was folded: *in folio, in quarto, in octavo, in 16ths*, and in exceptional cases, *in 32nds*[33].

The printing press was thus the first truly modern industry, involving a number of actors: authors, booksellers-editors, printers, stationers, binders, punch engravers, smelters of characters and the manufacturers of the press itself[34]. This industry operated based on standards that guaranteed the

33 In the 18th century, this format was often reserved for libertine novels.

34 Various types of presses were developed to manufacture paper pulp, then paper, as well as for binding and, of course, printing.

interoperability of tools and the homogeneous production of the semi-finished products. For example:

– standardizing the dimensions of a stationer's tools: presses, trays and a frame with a screen stretched over it;

– de jure typographic standards that were often defined with State support.

Typographers played an essential role in the standardization of printing: Claude Garamont[35], Christophe Plantin[36], Pierre Simon Fournier (who created the *Fournier point*, a typographic measurement that was the predecessor of the *Didot point*[37]), John Baskerville, etc.

Printing became the catalyst for the systematic collection of knowledge. As David Hume wrote to his publisher, "The power which printing gives us of continually improving and correcting our Works in successive editions appears to me the chief advantage of that art"[38]. Even today, *publishing* remains a major tool for the evaluation and universality of science.

1.4.1. *The* Grecs du Roy *and the standardization of the typographic point*

The *Grecs du Roy*, which was a set of Greek typeface punches commissioned for King Francis I of France, represents a fascinating study in typography. This typeface responded to the difficulty with scholarly study of Greek texts at the time and, above all, responded to the need to collect and translate texts so that publishers could disseminate them among a wider, educated public. This enterprise thus became one of the chief humanistic standardization challenges of the Renaissance. The central challenge

35 Known as the creator of the Garamond fonts (with a "d" and not "t"), which were notably used by the Venetian publisher Alde Manuce.

36 The *Plantin* font was one of the sources of inspiration for *Times New Roman*.

37 The Didot dynasty, which created font families as well as de facto standards for correcting proofs.

38 Cited by Élisabeth Eisenstein (1991). In the same work, she explains that printing enabled astronomical observations to be gathered and compared exhaustively, allowing Copernicus's heliocentric theory to emerge. She highlights the role of the standardization of astronomical texts and tables, which allowed the inconsistencies in the geocentric model to be more clearly seen.

was that as with any handwritten text, the *standards for the letter forms* necessarily change and transform over centuries (from the seventh century BCE in Byzantium to the fifteenth century CE) and between regions (from Sicily to the Indus). Francis I, on the advice of Guillaume Budé, desired to make his kingdom the center of humanistic studies. He therefore decided to create printed versions of the Greek manuscripts from royal collections. Following the King's commission, between 1543 and 1555 Claude Garamont engraved the punches that would allow the printing of the characters that are today known as the legendary *Grecs du Roy* (the King's Greek letters). The original punches, preserved in France's *Imprimerie Nationale* (National Printing Press), are today considered historical monuments. Garamont engraved three different sizes: a medium size or *gros romain*, a small size or *cicero*, and a large size or *gros parangon*. These letters were designed by faithfully reproducing the Greek writing and multiple ligatures of Angelo Vergecio, a Greek copyist and calligrapher from Crete who was active in Venice between 1530 and 1538 before being put in charge of King Francis' royal collection of Greek manuscripts in Fontainebleau.

The *Didot typographic point* is another example of standardization and also posed a challenge for metrological standards. To a non-specialist, establishing a metrology of typography may seem easy. The apparent ease with which we select a font size for a typeface in a word-processing software today seems to indicate that there is a universal measurement for typographic writing. However, typographic points have been standardized to respond to the needs of professional typographers working with traditional lead fonts, as was the case in artisanal presses even in the 1960s.

To understand why such a measurement was useful, it helps to move away from quantifying the dimensions of text typed in a word[39]. In reality, the only data that an author would be interested in would be the number of characters, with or without spaces. The remaining considerations are for publishing and typesetting. Printing, which earlier measured characters in the *Didot point*, today uses the *pica*[40].

39 This criterion is not very relevant except for knowing whether a text will take up a greater or lesser number of pages.

40 A DTP (desktop publishing point), often called a *pica point*, corresponds to 1/72nd of the international inch, or 0.351 mm or 0.94 of a Didot point.

However, it would be erroneous to think that this measurement is universal. In typography, each character font must consider the area occupied by the *eye* of a letter (the printed part of the character), which falls within the *height of the font*[41], a rectangular shape defined by the height of the mold and measured in the *Didot point.* The typographer-printer must have a unit of measurement that allows them to set texts in horizontal lines. The typographic point, adopted by consensus, guarantees a perfect alignment of lines regardless of the font used.

By the end of the 19th century, American and British printers began to use typographic points based on the *pica*, which is 1/72nd of the international inch. Many disputes broke out over how to precisely define this value, which was a crucial commercial question for dominating the font market. For the amateur typographer in us all, the typographic point (*Didot* or *pica*) allows us to appreciate the relative size of the characters within the same font. In simple terms, size 8 < 9 < 12 < 14, etc. However, neither the *Didot point* nor the *pica point* is meant to allow us to understand the volume of the texts. They define a graphic chart. It must be emphasized that in 1978, the standard AFNOR NF Q 60-010 was published, defining the Didot point as the typographic unit of measurement in the international system. However, in 1975, the ISO had proposed a Didot point measuring 0.375 mm (or 0.2584% smaller), a value that was never adopted. It must be recognized that even among the most specialized standardizers, there has never been any consensus on the universal definition of the typographic point. The problem therefore remains just as complex today.

Today, certain publishing houses still share *galley proofs* before confirming that a text is *ready for the press*, although these are now the exceptions rather than the norm. In this context, it is still useful to have a knowledge of a small set of standardized proofreading signs.

1.4.2. *A revolution in perspective: standardizing a point of view*

With the appearance of perspective in art, it soon became a standard point of view and one that is fundamental even today in photography and cinema. The mastery of illusion in relief features emerged in Italy in the

41 Height of the inside of the mould in the direction of the letter. Not to be confused with the *character height*, which is the distance between the letter in relief and the base of the character in lead.

14th century. In 1425, Brunelleschi definitively imposed a point of view of a one-eyed, immobile spectator through a public demonstration in the Florence Baptistery. He presented the public with a *tavoletta*, a board pierced with a hole on which he had painted the Baptisery's façade. The painting stopped at the roof of the building and the tablet had a metallic mirror fixed to the portion above this, reflecting the sky. The spectators would look through the hole, holding a mirror in the other hand, thus superimposing the painting on the actual view.

Following this, the evidence of the illusion created for a single, fixed eye became the norm: *conical perspective* became the pictorial convention[42]. Leon Battista Alberti (1404–1472) theorized this principle in *De Pictura*, where he recommends that "a painter be instructed in the liberal arts, as far as possible, but […] above all, that he have a good grasp of geometry" (Alberti 1435). Let us not let the dates mislead us, however. Brunelleschi's demonstration took place in 1425, and the first handwritten Latin edition of *De Pictura* dates to 1435 – however, this book was printed only in 1540, around 100 years after Brunelleschi's demonstration.

The question of whether perspective was discovered or rediscovered from ancient knowledge is not of interest to us here. In a highly illuminating article, Luce (1953, pp. 308–321) cites Vitruvius, who talks about lost Greek texts (especially Democritus's *Actinography*), saying they describe: "how to draw the lines corresponding in the natural way to eyes and propagation of rays from the specified center point". What interests us here is that this discovery led to a radical cultural, scientific and technical transformation in the Renaissance, not only in painting but also in geometric thought. Certain painters and theoreticians explored the limits of this concept through techniques such as anamorphosis, slowed perspective and foreshortening.

This standard conical perspective would be implemented in the *camera obscura*, the *camera lucida*, the physiognotrace and film and digital cameras. This is the conventional representation through which we analyze the world even today. It can be said that thanks to this discovery and the social adoption of all its facets, whether esthetic or theoretical, there was an unprecedented transmission of technical knowledge. Perspective laid the foundations for technical design and had a lasting impact on our perception

42 From the 15th century, Masaccio, Francesco di Giorgio Martini and Piero della Francesca rivaled one another for pictorial and geometric skill.

of beings and objects, including technical objects. In line with this, we can state that it was only through a radical change in his point of view that Leibniz was able to propose the concept of the modern binary number system.

1.4.3. *Engraving and the standardization of technical presentations*

From the Renaissance onwards, there was significant technical progress made in the field of engraving. While the earliest engravings on copper appeared around the 14th century, wood carvings had existed for much longer. Some incunabula (books printed before 1500) were illustrated using woodcuts[43]. From the 15th century, intaglio engraving became widespread, especially to diffuse the work of painters. However, unlike woodcuts, these new techniques that required engraving on copper were incompatible (we would say *non-interoperable* today) with text typography. To print using a woodcut, ink is applied on the design in relief on the block, which is perfectly compatible with the printing of texts. The engraved block, cut to the same character height[44] as the characters in the texts, can thus be directly included in the compositor for the composition of the final page. On the other hand, engraving on copper (through etching or chiseling) required a separate printing process: after inking, the excess ink had to be wiped away, with ink only remaining in the etched depressions. The image was then transferred onto a dampened sheet and pressed using a specific press that was different from the presses used for typography.

Until the 19th century and the invention of wood engraving, traditional woodcuts offered a much lower level of precision than engraving on copper. For scientific and technical books, publishers therefore printed texts and

43 For example, *De Re Militari* (1483), the first printed book to include illustrations (woodcuts) and which discussed military techniques. Another example is the *Nuremberg Chronicle,* printed in 1493 and illustrated with 1,800 woodcuts.

44 The standard height of typographic characters is 0.918 inches in North America and Great Britain. This is the height of the character measured from the foot to the face of the type. In France, this measurement is 23.56 mm or 62 points, a measurement standardized in 1723 through a Royal Decree specifying that there must be 10 lines to every half *pied du roi* (older unit of measurement of length).

illustrated plates separately, which led to a strict separation between image and text[45] in the books. This separation would last until the middle of the 19th century, notably seen in the case of Diderot and d'Alembert's *Encyclopédie* where the plates were published in a separate volume (Diderot and d'Alembert 1751).

Gradually, technical works benefitted from integrated explanations that allied texts and images. Apart from perspective, the illustrations now included complementary plan views, elevated views, and cross-sections, whose geometric construction followed rational rules. From this point onwards, the reader of a technical project was no longer looking only for an illusion of perspective, but a standardized rationality that led to the emergence of technical design. In her essay on technical design, Madeleine Pinault-Sørensen clearly illustrates the progressive inclusion of images within technical design and decision-making processes. She says:

> Colbert gives technical design an importance that it had never before enjoyed. He wanted design to play the double role of memory and progress, and to use image to present all the monuments and machines in the kingdom in order to glorify the reign of King Louis XIV. [He created a] *Bureau des dessinateurs* meant to establish maps and plans in the kingdom and then [he founded] the *École royale des Ponts et chaussées* in 1747 […] The students received scientific and technical training. They had to know about architecture and the art of sketching, be able to prepare quotes for wooden or stone bridges and other public works and establish maps and trace them carefully in watercolors. [It was again Colbert who] gave a strong impetus to arts and professions by creating craft production centers and research programs for the Royal Academy of Sciences. (Pinault-Sørensen 2003)

Colbert was also behind the publication of the earliest plates for *Arts and Professions*, for which a truly standardized visual syntax was developed, with a series of illustrations for each profession. This model would be repeated in the plates used for the *Encyclopédie*:

45 A standard enforced in publishing, which necessarily led to cognitive patterns being formed.

> Each art would begin with a plate that served as the frontispiece, in the top third was a sketch, a 'condensed meaning' […] summarizing the chief operations, and in the lower two-thirds, the descriptions of the tools. The following plates would only contain a description of the objects. (Pinault-Sørensen 2003)

Diderot and d'Alembert's *Encyclopédie* also had a rationalized dictionary, initially only textual, with close to 3,000 plates (2,885, to be precise), although only 30 plates were initially planned. This *Encyclopédie* had a lasting impact on how the European elites in the 18th and 19th centuries thought about technology. It established a true standard for technical description in text, but with close association with images that were systematically codified and referenced. These images were annotated with indices (numbers, letters, scales) corresponding to the textual commentary on the plates. However, the contemporary standardization of design was carried out by Gaspard Monge by standardizing the corpus on descriptive geometry (which was scattered until this point) and by closely associating theory with a renewed practice of technical design (see section 2.2.2).

1.5. Metrological uniqueness, the engine of metrological prosperity

Although Great Britain and the United States were the last to adopt the metric system, we must not forget that, from the 11th century onwards, England had been the first country in modern times to unify its systems of weights, measurements and currency. Inherited from the Romans, this system was enforced by law and lasted for a millennium. William the Conqueror (1066–1087) had been able to establish stable fiscal institutions like the Exchequer and a general inventory of wealth in the kingdom in his *Domesday Book*, all by putting in place a unified system of weights and measurements, which was made legally binding throughout the kingdom in order to simplify data collection. It must be highlighted that by creating a list of feudal lands without creating a cadastral survey, the *Domesday Book* favored the barons by attributing vast lands to them. In the 16th century, this led to the highly unequal dynamic of *enclosures*[46]. Further, in 1624, English industry had a patents office (*Statute of Monopolies*). This social inequality favored high finance, trade (especially maritime trade) and industry. While the rest of Europe tried to move away from its feudal structures, Great

46 This dynamic indirectly pushed poor farmers toward factories run by aristocrats.

Britain had already entered into industrial modernity, and this was in large part thanks to its metrological unicity[47].

The marine or nautical mile

The nautical mile is equal to 1,852 m, which is 1 min of latitude. In a fluid space like the sea (or sky), when one is far from the coast and without any fixed point of reference, the only possible references in earlier times were astronomical angular references. These were calculated using a sextant and the measurement of longitude using a marine chronometer. In this context, decimality was a counterproductive concept. As we saw earlier, these instruments were instead graduated into degrees of angles, formed by dividing a circle in a geometrically logical manner ($6 \times 60° = 360°$, or six chords whose length is equal to the radius of the compass). In the geodesic system, the equatorial circle measures around 40,075 km, that is, an average length of around 1,855.3 m for 1 min of longitude at the equator. In 1929, the *international marine mile* was fixed by convention to 1,852 m, a universal value that was gradually adopted by all countries.

Box 1.3. *The nautical mile – an angular measure of length*

However, it would be wrong to assume that the Anglo-Americans were completely uninterested in a decimal metric system. British and American astronomers had approached this question, chiefly by trying to establish coherence between units of length, weight and time. Nonetheless, in daily life, the subdivisions of units of measurement and of English money offered greater flexibility than the decimal system, which only allowed a single division (2×5). For example, the *mile*, which was equal to 1,760 *yards*, can be then divided by 2 five times. The *yard* is equal to 3 *feet*, itself divisible into 12 *inches*. It is the same for other units, especially for currency, which makes it easy to use in everyday life and for trade. The British thus tended to retain these advantages.

If there is one domain where British sailors – or indeed any sailor or aviator in the world – have not given in, it is nautical measurements.

In Europe, until the 18th century, there was a counterproductive diversity of weights and measurements. Jaucourt's entry for *Measurement* in Diderot

47 Direct effect (weights and measurements) or indirect effects, such as the Domesday Book and enclosures.

and d'Alembert's *Encyclopédie* highlighted the total absence of coherence between the different systems:

> Entry: MEASUREMENT (*Government thereof*). It can be imagined that people would never agree to work in concert with the same weights & the same measurements; however, this is very possible in a country under a single master. Henry I, the King of England, established the same weights and measurements across all his lands; this was the work of a wise legislator, which he fully implemented in his kingdom and which has always been proposed in vain in this one. In 1321, Philippe V wished to execute it but died. Louis XI had the same thought, because, he said, a State must have only one law, one weight and one measurement. Do not protest that this was a specious project, full of problems in execution, and which upon closer study proved to have been in vain and a conflict of words, as the prices of things quickly follow their weight and measurement. Would it not be more natural to avoid this step, to prevent it, to simplify and facilitate the course of internal trade which has always been difficult, when we must constantly have in mind and before us rates of the weights and measurements of the various provinces in a kingdom, to adjust one's operations to this? (Chapelle et al. 1751)

By the end of the 17th century, the different European countries in the continent wished to unify their units of measurement without aligning themselves on any existing system, or adopting the English measurements. Taking the dimensions of the Earth or the length of a second pendulum allowed them to arrive at a universal consensus to define inter-coherent weights and measurements. In 1668, the English scholar John Wilkins proposed a coherent system of three units of measurements related to each other through astronomy and physics. In 1583, Galileo theorized the simple pendulum, apparently after having observed the oscillation of a pendulum in Padua cathedral, synchronized with his pulse. In 1659, the Dutch astronomer and physicist Christian Huygens established an algebraic relationship between the time, length and weight of a pendulum, and then filed the patent for the first pendulum clock. In 1665, Jean-Dominique Cassini (the first of a dynasty of astronomers) constructed a heliometer to update the sundial meridian line that had been installed in the San Petronio church in 1575. This brought him great renown and as a result he was appointed the astronomer at the Royal Observatory in Paris in 1669. He was thus an example of the hunt for scholars that all European states were engaged in.

John Wilkins's proposition in 1668 was a major methodological advance toward a *coherent scientific metrology*[48]. Several propositions emerged in parallel to promote a decimal system, notably by defining multiples and sub-multiples for units, which simplified calculations. In 1670, the French priest and scholar Gabriel Mouton proposed a universal unit of length, based on the measurement of a terrestrial meridian, defined according to a decimal system. In 1675, Tito Livio Burattini suggested that this unit be called the *metro cattolico* (universal measure). In 1703, Leibniz published the *Explication de l'arithmétique binaire* (Explanation of Binary Arithmetic). By theoretically extending to infinity the number of possible numerical bases, Liebnitz consequently reduced the primacy of the decimal system.

The English, who were pragmatic, did not concern themselves overmuch with the unification of weights and measurements. However, as a seafaring nation, their Parliament founded the *Board of Longitude* in 1714. This was a committee of experts in charge of allocating contracts and granting loans or subsidies to develop methods to determine longitudes, especially at sea. The compensation was fixed as a function of the precision of the proposed techniques and instruments: £20,000 for a method that determined the longitude within 30 nautical miles (56 km) or a half-degree; £15,000 for a precision of up to 40 nautical miles; £10,000 for precision within 1° (60 nautical miles). This gave the English a considerable advantage in the invention and improvement of measuring instruments. In France, a *Bureau des Longitudes* was only established in 1795, by the Convention, and its role was limited to scientific coordination and publication.

1.6. Measuring the Earth: metrology's scientific quest

Astronomers have been obsessed with measuring the earth since ancient times:

48 The following measurements were thus coordinated: (1) a *universal length* from which followed the computation of a *universal volume*; (2) a *universal mass*, defined as the quantity of rainwater contained in a cube whose edge was equal to the universal length; (3) a universal length, fixed at 38 Prussian inches, equivalent to the *length of a pendulum, the half-oscillation of which is equal to one second* (which itself is a non-decimal sub-unit of a 24-h day).

> In 205 BCE, Eratosthenes designed and carried out an experiment to measure the meridian of the earth from two points: Syene (located above the first cataract of the Nile, today known as Aswan and famous for the dam) and Alexandria. Eratosthenes, like all Greeks (at least since Anaximander in the 6th century BCE) considered the Earth to be a sphere […] The city of Syene is almost on the Tropic of Cancer […] At the same time, in Alexandria, 5,000 stadia to the north (i.e, around 800 kilometers from Syene), on the same meridian, the short and decentered shadow of an obelisk of known height was measured. This measurement made it possible to calculate the angle that the sun's rays made with the vertical, that is, 7.2 degrees. [Bernard Champion concludes by noting that] three centuries earlier, Eratosthenes was right and not Ptolemy. Eratosthenes had thus estimated the Earth's circumference at 250,000 stadia, or, taking one stadium to be 157.50 meters, 39,600 kilometers. This estimate was close to the actual figure of 40,000.07 kilometers. (Champion 2007, pp. 135–160)

An error of only 400 km over 360°! This was a level of precision that the *Board of Longitude* would undoubtedly have found remarkable. However, over the centuries, and even today, Ptolemy has remained better known than Eratosthenes, whose name is almost unknown.

In 1617, the Dutch physicist Willebrord Snell used triangulation to measure the distance between Alkmaar and Berg-op-Zoom, separated by 1°, with a margin of error of 4%. In 1670, Jean Picard and Christiaan Huygens measured one degree of the Paris-Amiens meridian. This triangulation was again used in 1701 by Jean-Dominique Cassini. In 1735, Charles-Marie de La Condamine was order by the Academy of Sciences to measure the length of 1° of the arc of the Earth's meridian close to the equator[49]. After many difficulties, the expedition completed this measurement of three degrees on the Quito meridian.

It was during this long quest that La Condamine adopted:

> the idea of using the length of a second pendulum at the equator, at the altitude of Quito, as the natural measure […] defined by the gravitational attraction of the Earth rather than an

49 Maupertuis and Celsius carried out other measurements in Lapland. In retrospect, these were considered to be less precise than La Condamine's measurements.

> arbitrary measurement, like the *pied du roi*, which would provide a *standardized instrument for all nations to use*. (La Condamine 1751)

By comparing these meridian measurements, whose degrees appear longer in the South than the North, a controversy arose over the shape of the Earth. It set the Newtonians (who believed the Earth was swollen at the equator and flattened at the poles, like a mandarin) against the Cartesians (who believed the converse, that the Earth was more rounded at the poles and flattened at the Equator, like a lemon).

1.7. Turgot, standardizer of metallurgy and metrology

In 1775, Turgot, who was then a Minister under Louis XVI was preoccupied by the question of weights and measurements and wrote to Charles Messier, astronomer and a member of the Academy of Sciences:

> 3 October [1775]. M. de Condorcet must have told you [M. Charles Messier, 1730–1817], of the project that I established through exact experiments on the precise length of the pendulum, which, it appears to me, must serve as a common reference and comparison term for all measurements that will be easy to reduce to this. However, the rotational movement and the shape of the Earth will vary depending on the different latitudes, the weight, and consequently, the length of the pendulum that is used to create oscillations of equal duration. We must therefore resolve to choose the length of the pendulum at a fixed latitude as the matrix measurement […] the 45th degree, which passes close to Bordeau, seems appropriate to me […] I had therefore resolved to request an astronomer to come here in order to carry out all the necessary observations to establish the length of the pendulum. (Turgot 1775)

However, Turgot's fall from power led to the project being abandoned before Messier could set out[50]. Turgot was, however, a remarkable politician,

50 Editor's note on Turgot's letters: "The unification of weights and measures in France had long been demanded; it was discussed at the Estates General of Orléans in 1560. If Turgot's ministry had lasted six more months, the metric system would have been fixed thirty years earlier".

energetic and exceptionally cultured. A friend of Voltaire and the Encyclopédistes (he had authored several articles in the *Encyclopédie* himself), he was a physiocrat, yet not dogmatic. When he was a tax collector at Limoges, he had written a thesis called *Mémoire sur les mines et carrières* (Brief on Mines and Quaries) and another on *Marques des fers* (Protection of Native Iron), in which he protested against the protectionist standards imposed by the *Maîtres de forges (*Master Smiths):

> These standards are harmful to the specific requirements of industrial use […] To prohibit the importation of foreign iron, therefore, is to favor the iron master not only at the expense of the domestic consumers, as in the ordinary cases of prohibition, […] Now there are certain kinds of iron which our Kingdom does not supply, and which must be obtained abroad. With regard to steel, it is well known that very little of it is produced in France, that this kind of production is only just in the experimental stage, and that, however successful the trials may have been, it may take half a century perhaps before enough steel can be produced in France to supply a reasonable part of the use made of it by manufactures. (Turgot 1773)