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SOCIETY FOR THE HISTORY OF TECHNOLOGY

HISTORICAL PERSPECTIVES ON TECHNOLOGY,
SOCIETY, AND CULTURE

A SERIES EDITED BY PAMELA O. LONG AND ROBERT C. POST

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**TECHNOLOGY, SOCIETY, AND CULTURE
IN LATE MEDIEVAL AND RENAISSANCE
EUROPE, 1300-1600**

BY PAMELA O. LONG

A PUBLICATION OF THE SOCIETY FOR THE HISTORY OF TECHNOLOGY
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Cover Illustration: Women preparing wool, an illustration from a fifteenth-century manuscript. The servant on the right is combing wool, using vertical spikes set in a block of wood. In the center a servant cards the wool with a pair of carders. On the left the lady is spinning wool, drawing it down from the distaff. At the top, a woman is winding the warp yarn in preparation for the loom (Royal Ms. CV. f. 75, by permission of the British Library).

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SERIES INTRODUCTION

Technology reflects and shapes human history. From hunting and gathering cultures and the establishment of neolithic villages, farming, and food storage techniques to the development of metallurgy, ceramics, and weaving; firearms, printing, and mechanized power; and automation, electronics, and computers, history and technology have been integral with one another. The role and function of specific technologies—flint tools in the paleolithic and pottery in the neolithic, the stirrup in the Middle Ages, gunpowder and the mechanical clock in the thirteenth century, printing presses in the fifteenth and sixteenth, the steam engine in the eighteenth, factories in the nineteenth, and the automobile and nuclear power in the twentieth—are all subjects of an expansive scholarly literature. Throughout this literature are animated controversies concerning the choices made among competing techniques for attaining the same end—whether automobiles would be powered by steam, electricity, or internal combustion, for example, or whether electronic computers would be analog or digital.

Yet for all its importance, technology and its mutual interactions with society and culture are rarely addressed in high school, college, or even many university history courses. When scholars unfamiliar with its rich historiography *do* consider technology, they typically treat it as inert or determinate, lending their authority to the fallacy that it advances according to its own internal logic. Specialists in the history of technology now recognize the importance of “social constructivism”—technologies succeed or fail (or emerge at all) partly because of the political strategies employed by individual, group, and organizational “actors” who have conflicting or complementary interests in particular outcomes. Many of us believe that success and failure is contingent on inescapable physical realities as well as ambient sociocultural factors. But there is no doubt that technological designs are shaped by such factors; nor, indeed, that the shaping of technology is *integral* to the shaping of society and culture.

This joint venture of the American Historical Association and the Society for the History of Technology draws on the analytical insights of scholars who address technology in social and cultural context, whether their discipline be history or another field in the humanities or social sciences. Authors of these booklets may be concerned with the effects of particular technologies on particular constituencies; with the relationship of technology to labor, economics, and the organization of production; with the role technology plays in differentiating social status and the construction of gender; or with interpretive flexibility—namely, the perception that determinations about whether a technology “works” are contingent on the expectations, needs, and ideology of those who interact with it. Following from this is the understanding that technology is not intrinsically useful or even rational; capitalist ideology in particular has served to mask

powerful nonutilitarian motives for technological novelty, among them kinesthetic pleasure, a sense of play, curiosity, and the exercise of ingenuity for its own sake, a phenomenon known as technological enthusiasm. As evidence of this, many modern inventions—from the telephone to the automobile to new materials such as celluloid and aluminum—met only marginal needs at the outset. Needs with any substantial economic significance often had to be *contrived*, thereby making invention the mother of necessity.

There are many definitions of technology. Often they are ahistorical, particularly those that define technology in terms of applying science to industrial and commercial objectives. Sometimes technology is defined as the way that “things are done or made.” While this is not a historian’s definition per se, it becomes that whenever one asks how things were done or made in a particular way in a particular context and then analyzes the implications of taking one path rather than another. Lynn White Jr., a historian who served as president of both the Society for the History of Technology and the American Historical Association, called this “the jungle of meaning.” While the notion that technology marches of its own predetermined accord still has a strong hold on popular sensibilities, specialists in the interaction of technology and culture now understand that it cannot do anything of the sort. Technology is not autonomous; rather it is impelled by choices made in the context of circumstances in ambient realms, very often in the context of disputes over political power. Once chosen, however, technologies themselves can exert a powerful influence on future choices.

To some extent, definitions of technology vary from one discipline to another. We believe that defining it as “the sum of the methods by which a social group provides themselves with the material objects of their civilization” is sufficiently concrete without being too confining and without being misleading. It is important to specify the word *material*, for there are of course “techniques” having to do with everything from poetics to sex to bureaucratic administration. Some might go further and specify that “material” be taken to mean three-dimensional “things,” and this seems satisfactory as long as one bears in mind that even an abstraction such as a computer program, or an idea for the design of a machine, or an ideology such as technocracy or scientific management is contingent for expression upon tangible artifacts.

“Technology” is a modern word, dating to the early nineteenth century. Its first well-known usage was in an 1831 treatise by Jacob Bigelow entitled *Elements of Technology*. For some time after that—and maybe even today—it was not a term known to every culture. “Mechanical arts,” used in medieval and early modern Europe, is not entirely synonymous, since this term included things like painting and sculpture as well as machinery, mills, and the like. Technology encompasses various actors’ categories in diverse historical cultures, and that is part of the reason why

contemporary scholars define it variously. We believe that the complexity of definition, conceptual categories, and methodologies is instrumental in making the history of technology such a fascinating and fruitful area of inquiry. In these booklets, each author may be grounding his or her inquiry on somewhat different assumptions about the nature of the subject matter.

“Every generation writes its own history,” said Carl Becker. In commissioning and editing these essays, we have sought to have each one convey a broadly informed synthesis of the best scholarship, to outline the salient historiographical issues, and to highlight interpretive stances that seem persuasive to our own generation. We believe that historians of technology are poised to integrate their inquiries with mainstream scholarship, and we trust that these booklets provide ample confirmation of this belief.

Pamela O. Long
Robert C. Post
Series Editors

INTRODUCTION

In his *New Organon* published in 1620, Francis Bacon exclaims enthusiastically about the great power and value of new discoveries. Nowhere is this more obvious, he writes, than with printing, gunpowder, and the compass. These three inventions have changed "the whole face and condition of things throughout the world, in literature, in warfare, and in navigation."¹ Historians of technology who focus on the centuries between 1300 and 1600 are also fascinated by such inventions. They study both new inventions and traditional crafts and technologies as integral to society, exploring how the old and new fit together. They see material production as intrinsic to society as a whole, and investigate how technologies influence and are influenced by issues of gender, class, political power, and other aspects of society and culture.

During the late Middle Ages, crafts, building construction, and material processes of all kinds were known as the mechanical arts. These included agriculture; the manufacture of goods ranging from wool cloth to fine glassware; painting and sculpture (today classified as fine arts); the production of consumables such as bread and beer; and activities such as mining, metallurgy, and hydraulic engineering. The mechanical arts were distinct from the liberal arts and from higher disciplines such as medicine, theology, and law. These subjects were taught in Latin at the universities, whereas artisans and craft workers acquired their trades through apprenticeships, either informally in households or by contract in workshops. Despite their lower status, the mechanical arts deeply affected almost every aspect of culture and society.

The centuries between 1300 and 1600 are characterized by dynamic cities, especially in northern Italy, southern Germany, the Netherlands, and England. Commercial capitalism developed rapidly and encompassed new methods of banking and credit, long-distance trade, manufacture and craft production of all kinds, and large-scale building construction. Especially in the cities, a great expansion of the decorative arts occurred, from painting to fine furniture to majolica ware (tin-glazed, decorated earthenware), as the elite classes increasingly engaged in conspicuous consumption. Yet without forgetting the importance of late medieval urbanism, it is important to keep in mind that during this entire period the great majority of people on the European continent and the British Isles lived in rural areas and spent their lives working in agriculture.

By the first quarter of the fourteenth century, Europe was seriously overpopulated relative to its agrarian capacity. Areas such as the Lowlands and England were ravished by famines in the 1320s and 1330s. Then in 1348 the Black Death swept across Europe. Whatever the actual disease

that caused it (historians are no longer sure it was the bubonic plague), the Black Death was a demographic catastrophe of unimaginable proportions. One-third to one-half of the population of Europe died. Yet from this demographic trauma there may have been some benefits for those who lived. Europe went from overpopulation to a shortage of labor—an advantage to workers who had survived and could draw higher wages. Historians dispute whether the Black Death spurred a burst of technological ingenuity resulting in labor-saving devices. David Herlihy contends that it did, whereas Samuel Cohn Jr. points to the existence of as much evidence for technological innovation before the catastrophe as after.²

Recurring endemic plagues were still afflicting European populations in 1600. Yet much had changed. Wealthy bankers and urban patriciate classes were rapidly turning themselves into a landed aristocracy. Navigation and exploration had led to the European discovery of new lands that Europeans called the Americas. Global expansion, exploration, and often brutal conquest brought new products, new riches, and new views of the world. By 1600 the Catholic Church had been split apart by the Protestant Reformation but also had reformed itself by means of the Council of Trent (1545–63). Motivated in part by religious conflict, warfare became endemic in the second half of the sixteenth century. Warfare itself underwent a process of transformation brought about by gunpowder artillery and the new bastion fortifications designed to defend against that artillery. Other technologies developed as well. During the sixteenth century, Europe was flooded with broadsheets and books produced by the printing press, invented in Germany around 1450. Finally, such newly developing territorial states as France, England, and Spain exercised a growing influence upon political organization, economic production, and technological development.

These transitional centuries are the focus of several long-standing debates concerning economic development that are relevant to invention and technology. One group of economic historians, including M. M. Postan and Emmanuel Le Roy Ladurie, saw the period in terms of a demographic crisis in which traditional agriculture was unable to feed a growing population. In a famous essay, Robert Brenner argued against this view, suggesting that the economic crises of the period can be seen in terms of a class struggle between landlords and tenants. In France, Brenner argued, smallholders and tenants gained greater autonomy. The lack of technical innovation that resulted led to economic stagnation. In England, in contrast, large landholders gained the upper hand, developing commercial agriculture at the expense of small landholders with the help of technical innovations. More recently a revisionist view holds that rather than operating at their technical and productive limits, societies in these centuries were operating below that capacity. Technology itself did not constitute the limiting factor, as earlier scholars on various sides of the “Brenner

debate” assumed. Rather, for complex reasons, there were significant variations in the rate and intensity of technical innovation from one locale to the next.³

While the “Brenner debate” concerns primarily agricultural technology and production, another discussion among economic historians centers on rural industry by peasants involved in craft production for market, or “proto-industrialization.” Defined by a group of economic historians in the 1970s, proto-industrialization involved rural manufacture for distance markets, an activity they associated with the development of commercial agriculture. The concept of proto-industrialization has been used in several diverse stage-theories of economic development, either from feudalism to capitalism, or in another version, as the first phase of an industrialization process. For proto-industrialization to be present, its proponents insist that it must include, among other things, an accumulation of technical knowledge which would be helpful as economies developed into true industrialization. The term has acquired a large number of meanings, and motivated much research on regional economies from the fifteenth to the eighteenth centuries. While some historians argue against its utility as part of a model for economic development, many others have refined its meaning and used it as a heuristic tool for further empirical research.⁴

Most historians agree that the period between 1300 and 1600 was an age of transition, but they disagree about the utility of the term “Renaissance.” This term came into general use after Jacob Burckhardt wrote his brilliant essay, *The Civilization of the Renaissance in Italy* (1860). Burckhardt characterizes the Renaissance in terms of the rise of individualism, the development of the state as a “work of art” (that is, an entity created at will by individual princes and rulers), the secularization of culture, and the dawn of the modern world. More recently, historians have debated and often rejected such characterizations and have used the term not to mean a historical period, but to indicate a cultural movement. An important aspect of such a movement was Renaissance humanism, which entailed the revival of classical Latin, the intense investigation of ancient texts and ruins, and the study of rhetoric and history in contrast to the emphasis of university scholasticism on logic and philosophy. Some historians reject the term Renaissance altogether and put in its place “late medieval and early modern,” a period that usually extends from about 1350 to 1800; some simply use “early modern,” a period encompassing about 1500 to 1800.⁵

Close study of social and economic phenomena underscores the complexity of change and tends to undermine sharply defined periodization. Not surprisingly, social and economic historians tend to use the term “late medieval,” rather than “Renaissance,” since they focus on long-range phenomena often involving slow rates of change. From another point of view, Joan Kelly’s famous question, “Did Women Have a Renaissance?” and

her conclusion that they did not, subverts a view of the Renaissance as a time of progress and cultural resurgence. John Muendel's study of fourteenth-century Florentine mills and their relevance to urban design and economic activities suggests a far more complex cultural and economic history than a dichotomous periodization would allow. Marvin Trachtenberg's study of Florence's fourteenth-century *piazze*, or public squares, repudiates the medieval/Renaissance dichotomy in another way. Showing the "medieval" *Piazza del Duomo* and the *Piazza della Signoria* to be examples of rational urban design intrinsically connected to the political and social interests of Florentine elites, his study revises the traditional view that medieval organic, haphazard urban growth was replaced by the rational urban design of the Renaissance.⁶

Yet the term "Renaissance" has proven surprisingly resilient both with the public at large and among many professional historians, some of whom configure the term in ways relevant to historians of technology. For example, Paula Findlen defines the Renaissance as a cultural phenomenon, which features the "collection, creation, and celebration of objects." Findlen notes an increasing interest and investment in "culture," that is, antiquities, paintings, sculpture, and manuscripts. In her analysis, materialism (meaning a new appreciation for material things) developed significantly in these centuries. Lisa Jardine, focusing on England, suggests that culture came to be dominated by worldly goods. Richard Goldthwaite notes the increase in building activities among elites and the upsurge in spending of princely and patriciate households on a myriad of items, including private art, as significant aspects of Renaissance economy and society.⁷

Goldthwaite addresses a long-standing discussion among economic historians about whether the Renaissance was a time of economic depression. This discussion, which centers on Italy in the fourteenth and fifteenth centuries, was initiated by Carlo Cipolla's claim that gains in agriculture in Italy compensated for a decline in trade and industry. Roberto Lopez and Harry Miskimen criticized Cipolla on the basis of the qualitative nature of his evidence, arguing that the towns were "hungry parasites" living off the "half-starved" countryside around them. Cipolla countered that when *per capita* income is considered in analyzing growth, stagnation, and decline, the picture is far more positive. Local studies such as that of John Muendel focusing on the Casentino countryside near Tuscany, for example, show a prosperous economy augmented by iron, the fulling of wool cloth, and saw mills owned and operated by peasants. Goldthwaite focuses rather on the towns, noting that the upsurge in patronage for art of all kinds and building construction in particular, successfully balanced declines elsewhere.⁸

Whether the period was one of economic depression, the view of the Renaissance as a cultural movement has been closely tied to both large-scale construction and the accumulation of worldly goods. It is thereby tied to the production and manufacture of those goods—that is, to issues

of technology. This is not to argue that either the period itself or cultural movements within it necessarily represent the early development of modernity, as Burckhardt claimed. Numerous aspects of European culture in these centuries, including attitudes and approaches to technologies, were unmodern. A contextual view of the history of technology—the approach taken here—does not look for modernity, or for signs of "progress" or "technological creativity" conceptualized from our own culture's point of view; nor does it look for causes of "Western superiority" as several economic historians recently have done.⁹ Rather, a contextual methodology attempts to understand technologies both customary and innovative within the ambience of the historical cultures in which they are found, and to understand their meanings for the diverse people who lived within those cultures.

AGRICULTURE AND FOOD PRODUCTION

A fundamentally important group of technologies involved growing crops and raising livestock and other animals. Agricultural practices varied widely throughout Europe, in part because of geographical variations. In the most general terms, Europe can be divided into two large agricultural regions. The Mediterranean region is characterized by light sandy soils and dry summers, and requires irrigation for summer crops. The northern plains receive significant summer rainfall and have heavy, wet soils. These variations resulted in different crops, the use of a range of tools and implements, and the development of diverse technologies. Perhaps best known among these is the heavy wheeled plow (**Figure 1**), which appeared during the early Middle Ages in northern Europe and was especially suitable for the region's heavy soils. Differing significantly from the scratch plows of the Mediterranean, it was constructed with a colter or iron knife that cut the furrow, an iron share that cut the soil horizontally, and a wooden mold board that turned the clod.¹

Developments in agriculture after 1300 often involved gradual changes, some of which became highly significant. For example, crop rotation was a standard agricultural technique for preventing soil depletion, and medieval Europe increased productivity in general by changing from a two-field to a three-field rotation system. Three-field rotation involved a yearly cycle in which a third of the land lay fallow, a third was planted in spring crops, and a third in fall crops. Yet rotation practices differed widely from one area to the next, and underwent developments more complex than a single change from two- to three-field rotation suggests. For example, in Italy in the fourteenth and fifteenth centuries, increasingly intricate systems were adopted, including rotation of beans and flax, hemp and grain, and millet and grain. In irrigated areas, the fallow sometimes could be eliminated altogether; elsewhere it was often limited to a few weeks or months. In northern Europe there was also a tendency to reduce the amount of time a field was left fallow.²

Another defense against soil depletion involved fertilization, including burning of stubble and grass, and spreading the ash of wood burned elsewhere. In the Appenine mountains near Bologna, peasants burned wood regularly to produce ash for sale as fertilizer. Peasants throughout Europe and England also fertilized their fields with human and animal waste. A basic problem in many areas was the production of sufficient animal feed. Grain shortages increased pressure to produce food for humans, not animals. Yet when villagers slaughtered animals for lack of pasturage, less manure meant less fertile fields. One solution to the perennial problem of animal pasturage was transhumance—the practice of driving herds to the

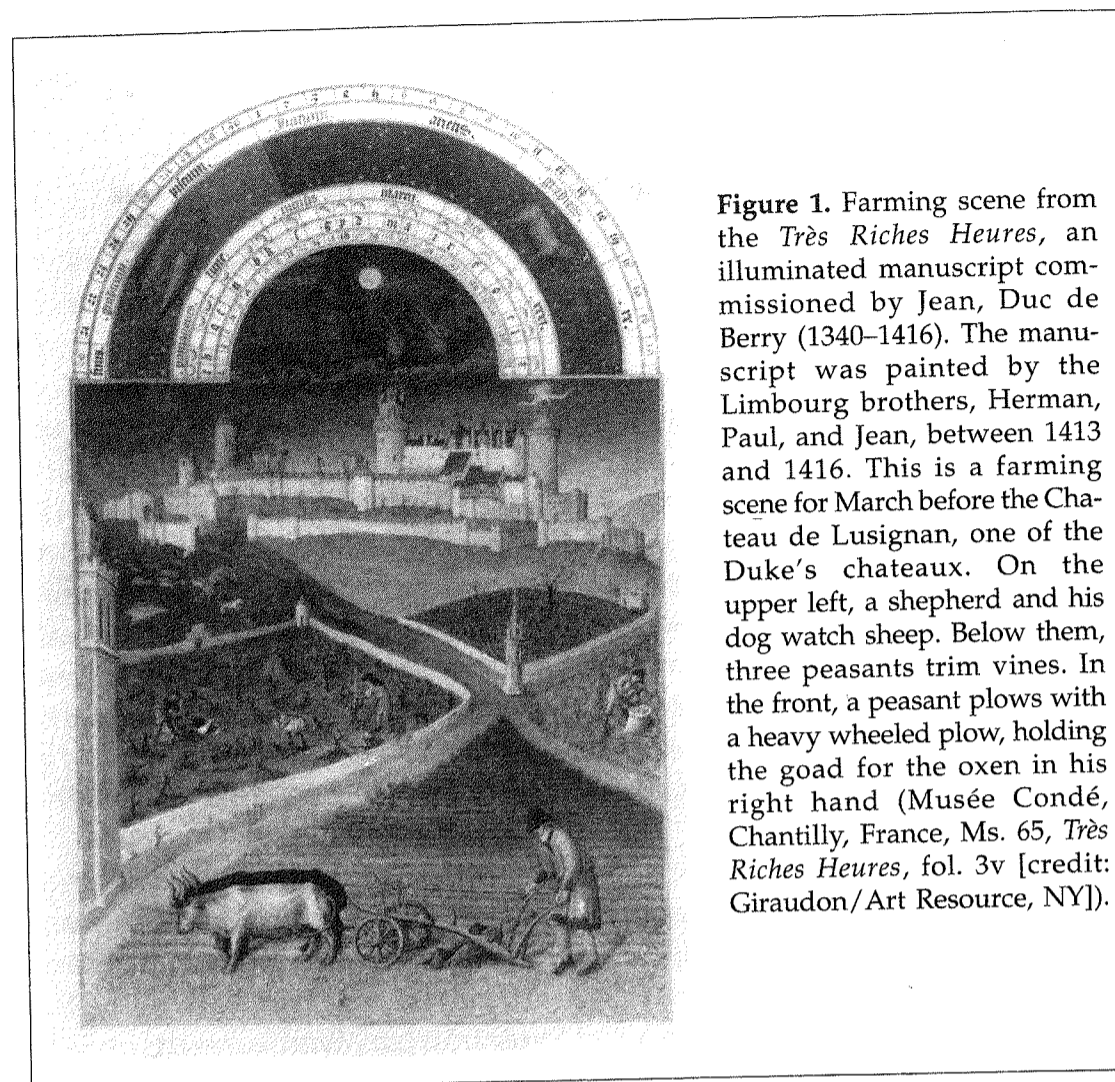


Figure 1. Farming scene from the *Très Riches Heures*, an illuminated manuscript commissioned by Jean, Duc de Berry (1340–1416). The manuscript was painted by the Limbourg brothers, Herman, Paul, and Jean, between 1413 and 1416. This is a farming scene for March before the Chateau de Lusignan, one of the Duke's chateaux. On the upper left, a shepherd and his dog watch sheep. Below them, three peasants trim vines. In the front, a peasant plows with a heavy wheeled plow, holding the goad for the oxen in his right hand (Musée Condé, Chantilly, France, Ms. 65, *Très Riches Heures*, fol. 3v [credit: Giraudon/Art Resource, NY]).

mountains to graze in spring and summer, and then back down to the plains in winter. Shepherds practiced transhumance in many parts of Europe, including Languedoc in southern France where they drove the sheep back and forth across the Pyrenees Mountains. The paths of transhumance could carry more than sheep and shepherds, as Emmanuel Le Roy Ladurie demonstrates in his study of the Albigensian heresy and its transmission along the transhumance paths of the Pyrenees.³

Some developments in agriculture involved changes in customary arrangements between peasants and landholders. For example, in Italy commercial leases gradually took the place of traditional demesne farming. In the latter, part of the arable land of the village called the *desmesne* (usually about a third to a half of the land) was worked by the peasants for the lord. The lord also received rents in kind consisting of every type of product raised by his tenants, from chickens to apples. This system involved traditional arrangements whereby the peasants possessed customary rights to work some land for themselves. The new system of commercial leases involved simple contracts. Those giving leases included not only traditional landowners, but also entrepreneurs from the towns. Landlords gave leases, sometimes involving entire farms with livestock and buildings, in exchange

either for fixed rents (usually paid in food, especially grain) or sharecropping. The practice of leasing brought about a consolidation of holdings and the redevelopment of great estates.⁴

The rate of change for some regions is a subject of disagreement among historians. Eric Kerridge argues that beginning in the sixteenth century an "agricultural revolution" occurred in England. Important innovations included convertible husbandry; the draining of fens; seasonal inundation of meadows, called "floating meadows"; and marling (fertilizing with marl, a mixture including clays and shells, effective in lime-deficient soils). Convertible husbandry abolished the distinction between permanent arable (cultivated) land and permanent pasture: the same land was alternated between pasture and planting. This new practice increased the productivity of both crops and livestock. Crop yields were higher on land that had rested under grass while fertilized by the manure of grazing animals. Likewise, pastures grown on recently cultivated fields provided richer nourishment, thereby increasing the health, weight, and productivity of the animals. The new system ended the necessity for fallow fields. The English innovation of floating meadows involved the construction of extensive irrigation systems that covered entire fields with water for certain parts of the year. Flooding deposited silt, protected against frost, and provided adequate water in the summer, thereby increasing productivity. While Kerridge persuaded agricultural historians that these developments occurred earlier than they had thought, many question whether they occurred so rapidly as to justify the term "agricultural revolution."⁵

An important change in field use both in England and on the continent involved the "enclosure" movement. Traditional medieval agricultural practices divided "commons" into parcels of land that villagers cultivated cooperatively or used in common for pasture. An enclosure would terminate common land use by fencing or otherwise cordoning off land for private use. Landlords often enclosed land and then leased it to tenants. In early sixteenth-century England, landlords undertook enclosure in response to high wool prices, fencing off arable land and converting it to pasture for sheep. Then, after 1550, they enclosed much land and cultivated it in response to high grain prices. When enclosure occurred, for whatever reason, it ended traditional village strip farming by creating individual holdings. Enclosure disrupted communal regulations, usually to the detriment of the peasantry and to the benefit of private owners and their tenants. Most historians once believed that enclosure, although it often involved a brutal process, enhanced agricultural productivity. However, recent research has modified this picture. Rather than causing radical disruption, enclosure helped to solidify divisions of wealth and property ownership already evident in medieval villages. Historians have interpreted apparent increases in productivity as resulting not from enclosure *per se*, but from the landlords' greater power to acquire a larger proportion of the products. At the same time, they have reevaluated traditional village strip farming as more productive than they previously had thought.⁶

Irrigation and hydraulic engineering significantly influenced the development of agriculture in certain regions of England and Europe. Irrigation systems were sometimes innovative—as in the English floating meadows mentioned above—but just as often they involved more traditional approaches. Thomas Glick shows that agriculture in Valencia on the Iberian peninsula was based on customary practices that sometimes were centuries old, such as the irrigated cultivation of orange trees. Traditional techniques included dams to raise water into irrigation canals, as well as the *noria*, or water wheel, that lifted water with buckets, and the *ganat*, a hydraulic system that used a series of wells connected underground to tap ground water.⁷

In other areas, irrigation brought about changing agricultural practices and products. In Italy's Po valley, for example, cattle breeding was made possible by the development of irrigation systems that allowed a large increase in the production of hay and fodder. In irrigated areas, grain, hay, and subsequently clover and alfalfa (sometimes called lucerne) took the place of grain and vines. Farmers gradually replaced sheep with cattle, using them as beasts of burden, milking them, and slaughtering them for meat.⁸

The Netherlands was profoundly dependent on hydraulic engineering. Rather than bringing water into fields, the problem there was to remove the water and hold back the ever encroaching sea. People in the Lowlands had constructed dikes since the eleventh century. They also developed complex legal and administrative systems to regulate dike construction, based most importantly on local regulatory committees called drainage boards. Dike construction involved diverse techniques that depended on local practice. Often villagers made dikes with an earthen core protected by straw and clay, bundles of reeds, or seaweed. In the fifteenth century, dikes constructed with heavy timber piles came into use. In the sixteenth century, hydraulic engineering became an ever more significant activity, the aim being to "lay dry" numerous inland *meers*, or lakes. Workers would construct an earthen bank around the *meer* and then surround this dike with a canal. Water lifting or pumping machinery powered by wind (drainage windmills) pumped the water out of the *meer* into the canal. To work properly the sails of a windmill must be turned toward the wind, a task complicated by the large size and weight of the machine. Hydraulic workers improved the drainage windmill with the invention of a rotary cap, a device that enabled the sails to be turned without having to turn the whole mill. The water, after being pumped into the canal, flowed downward by means of gravity or through sluices into a main canal or river. Drainage projects in the Lowlands put a significant amount of new land into cultivation during the sixteenth century.⁹

Throughout Europe and England crops varied depending in part on geography and soil conditions. Major cereal crops were wheat, rye, barley, and oats, along with others that added nitrogen to the soil, such as peas, beans, and eventually clover. The European conquest of the Americas led to the planting of new crops, most importantly the potato from the Andes region of South America, and maize, or corn. Other new-world crops such as

tobacco, coffee, and cocoa became staples of consumption even though they remained primarily imports. Livestock on village farms included cows and sheep, pigs, geese, hens, ducks, and sometimes pigeons and beehives. Woodlands, orchards, and vegetable gardens were important components of agricultural production.¹⁰

Agriculture involved preparing the soil, planting and maintaining crops, and caring for livestock. It also demanded the extensive labor of harvesting and preparing agricultural products for consumption, either as food for humans and animals or as materials for craft and industrial production. Products prepared for manufacturing processes included wool and linen for textiles; hides for shoes; and all kinds of leather goods, including parchment (sheepskin) or vellum (calfskin) to be made into books; tallow from the fat of sheep and cows for lighting; and wood gathered from woodlands for ships, vehicles, tools, furniture, and buildings. Some of this production was accomplished in the household; in other cases raw materials were transported to new sites.¹¹

An important example of processing after harvest involved the grinding of grain. Grinding was necessary if grain was to be used as flour. If it was to be consumed as porridge, however, a much coarser grain was sufficient and this could be produced in the household with a hand mill or mortar and pestle. Some households also ground wheat for flour with hand mills, operated by turning a handle attached to an upper concave stone rotating on a convex stone. Usually, villagers took the grain to the local miller, who maintained a large mill into which he poured grain through a funnel or hopper.

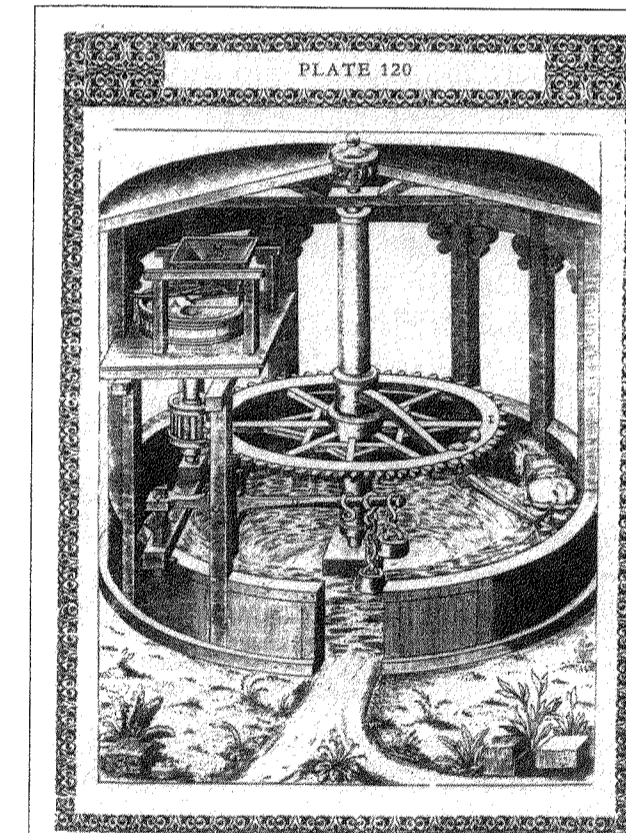


Figure 2. A horse mill from *The Various and Ingenious Machines of Agostino Ramelli*, first published in 1588 as *Le diverse et artificiose machine*. The horse turns a toothed wheel by means of a bar set into the wheel shaft. The wheel engages the lantern gear, changing the motion from horizontal to vertical. The shaft from the lantern gear goes to the undersurface of the upper stone. The grain to be ground is put into the hopper.

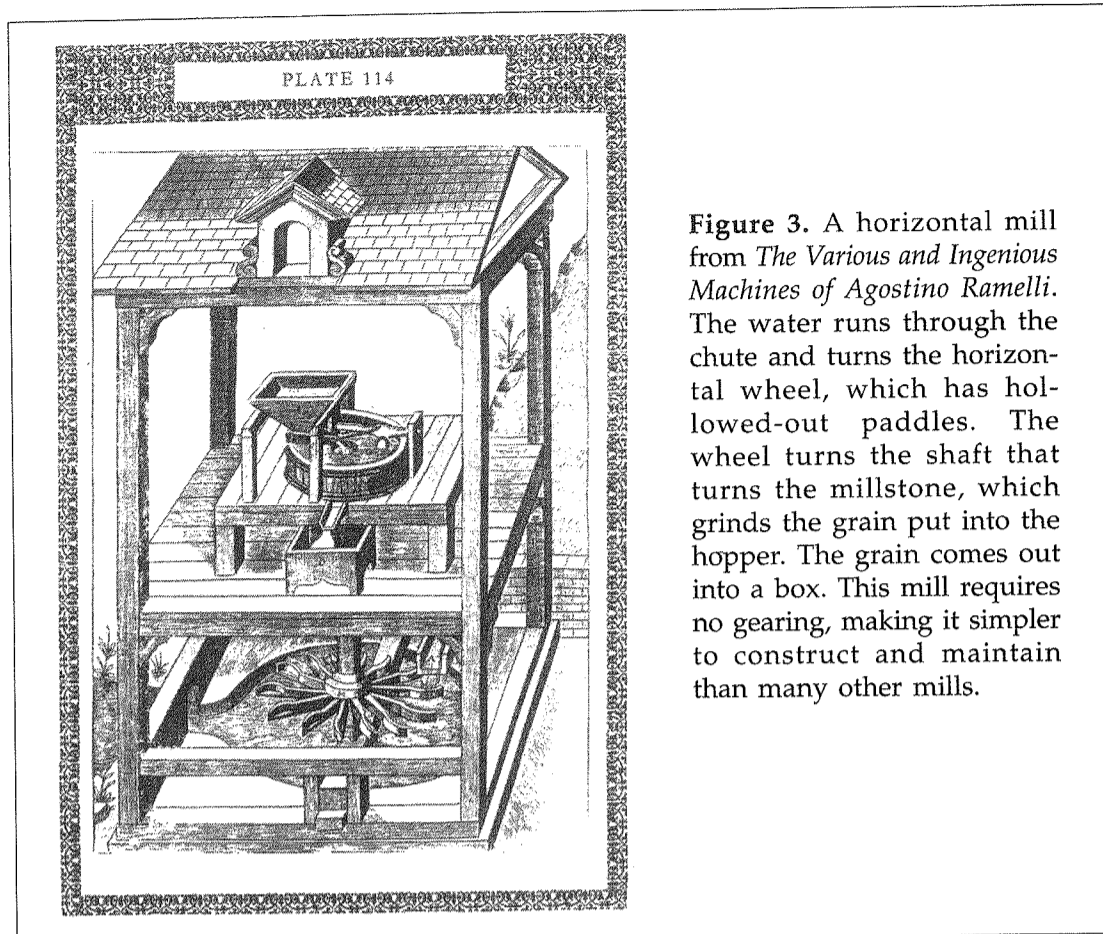


Figure 3. A horizontal mill from *The Various and Ingenious Machines of Agostino Ramelli*. The water runs through the chute and turns the horizontal wheel, which has hollowed-out paddles. The wheel turns the shaft that turns the millstone, which grinds the grain put into the hopper. The grain comes out into a box. This mill requires no gearing, making it simpler to construct and maintain than many other mills.

The grain fell into a hole at the center of a pair of millstones, was ground between the stones, and emerged as flour at the edges.¹²

Mills are classified according to how they are powered. Those for grinding grain include dry mills turned by horses or donkeys (**Figure 2**), windmills, and various kinds of watermills. Windmills appeared in Europe in the late twelfth century. They had four sails that needed to be turned toward the wind to work. The two most common windmills were the tower mill, in which the tower or turret was rotated, and post mills, which rotated around a fixed central post. Watermills were powered in various ways by moving water. The simplest watermill, the horizontal mill (**Figure 3**), consisted of a horizontal wheel with paddles, connected with a vertical shaft to a grinding stone. It required no gearing and was relatively easy to construct and repair. Vertical waterwheels, on the other hand, were mounted on axles and required gearing to transfer their motion to horizontal millstones. There were two kinds. The undershot waterwheel was powered by the force of the water moving under the wheel, whereas the overshot wheel was powered by water falling over its top. Although vertical mills were usually more powerful, they were also more complex, and more expensive to build and maintain. Richard Holt suggests that in places where powerful lords monopolized milling, vertical mills became the rule. Where individual peasants and small groups carried out their own milling, the horizontal mill often remained in use until modern times.¹³

Agricultural production throughout Europe usually involved the labor of the peasant family whose individual tasks were determined by gender and age. Historians have used a variety of sources to determine who did what. Barbara Hanawalt, for example, uses English inquest records of deaths by accident to investigate the kinds of work carried out by men, women, and children. Such records often indicate the task the individual was engaged in when the accidental death occurred. Manorial records and court records of various sorts provide other kinds of evidence for the division of labor by gender.¹⁴

Plowing, a basic task of cultivation, was a long and arduous labor. The husband worked the plow, while his wife or child might goad the ox. Harvesting involved all able-bodied members of the family. The men would reap with a scythe while women and children gathered and tied the bundles of grain (**Figure 4**). Separating the grain from its stalk with flails was usually men's work, as was winnowing (separating the grain from the chaff). Men also collected wood, took care of such large farm animals as horses and oxen, and dug drainage ditches.¹⁵

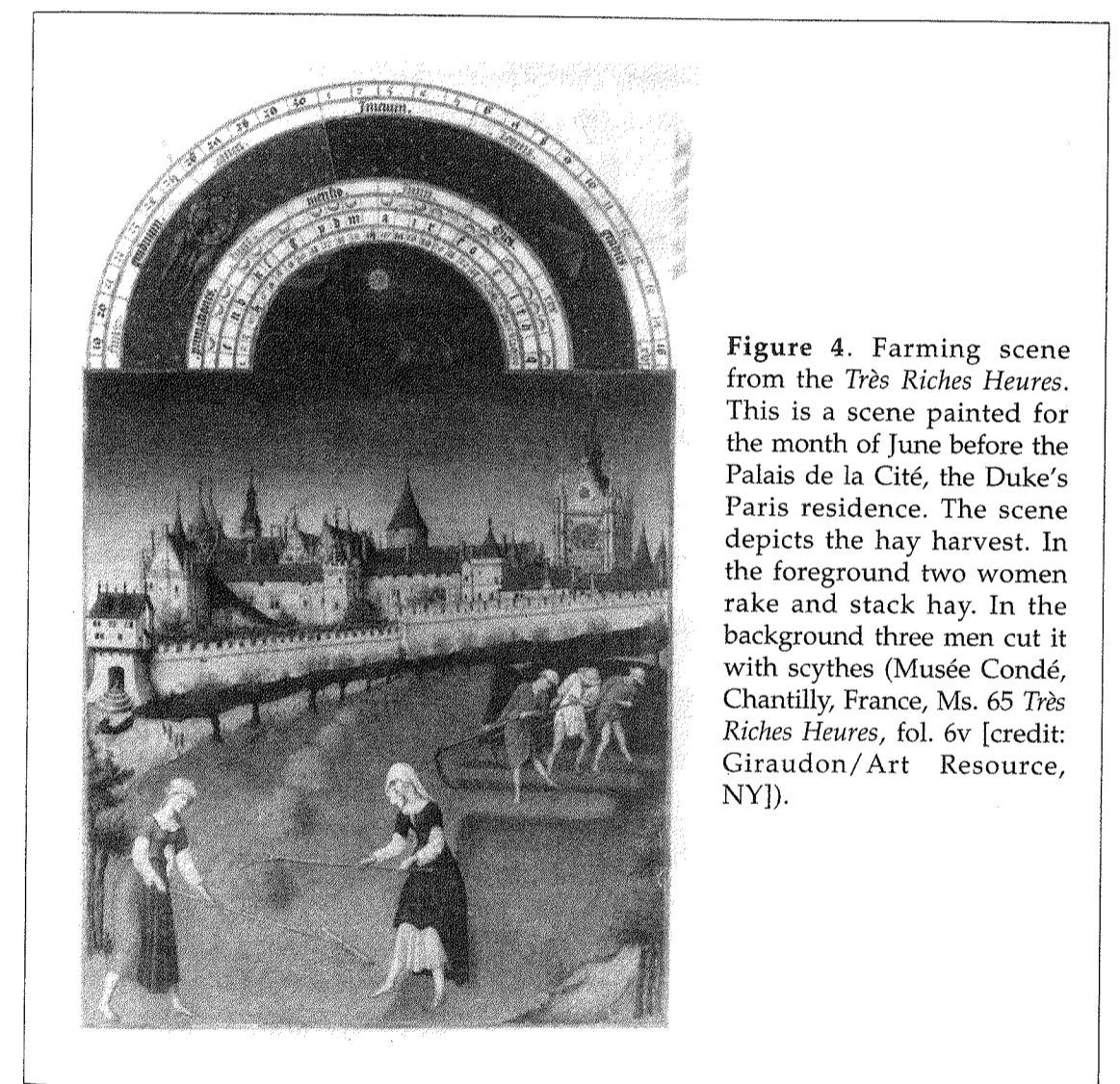


Figure 4. Farming scene from the *Très Riches Heures*. This is a scene painted for the month of June before the Palais de la Cité, the Duke's Paris residence. The scene depicts the hay harvest. In the foreground two women rake and stack hay. In the background three men cut it with scythes (Musée Condé, Chantilly, France, Ms. 65 *Très Riches Heures*, fol. 6v [credit: Giraudon/Art Resource, NY]).

Women bore, breast fed, and cared for babies and young children, as well as performing other arduous tasks of the household economy. They fetched water from wells for washing and cooking; milked cows and took them to pasture; made butter and cheese; maintained the fire; cooked; did laundry; took grain to the mill; kept poultry, geese, and hens; and cared for pigs, vegetable gardens, and fruit orchards. In the fields, they hoed, weeded, turned hay, tied sheaves, reaped, and gleaned (the backbreaking task of picking up stray grains in the field after a harvest). Some women were engaged in commercial baking and brewing operations, making products for sale. Judith Bennett shows that the industry of brewing was carried out and controlled by women in fourteenth-century England.¹⁶

It should not be assumed that a coherent, relatively uniform "peasant" class existed during this period. Rather, there is evidence of wide economic and status differentiations among families who engaged in agricultural labor that ranged from laborers paid by the day for seasonal work to relatively well-off tenant farmers. In addition, working the land and raising livestock were rarely isolated activities. Both men and women in many peasant families undertook numerous additional income-earning activities. Such families should not be thought of as self-sufficient subsistence farmers. Rather, they were involved in local markets. They purchased such products as bread and beer, and they paid for skilled labor from carpenters and smiths, among others; they also provided services for pay. Men might make extra income by carting—that is, transporting oil, wine, beer, or lumber. Although tailors fabricated much clothing, women sometimes made rough cloth at home. Women often supplemented income by spinning wool, and sometimes by weaving, or by beating flax and making linen thread.¹⁷

THE WOOL INDUSTRY

Clothmaking, especially wool cloth, was a fundamentally important industry in many parts of Europe. The most significant production centers developed in Italy, the Low Countries, northern France, and England. Making wool cloth was a complex process involving different kinds of workers and diverse work sites. At the beginning of the process, workers sheared the sheep, and then cleaned the wools by raking them in a large wooden tub containing hot water and lye or stale urine (a natural detergent because of its ammonia). After rinsing them in cold water, usually a stream, they separated the long fibers from the short. They dried the wool, placed it on tables or benches with narrow slats, and beat it with sticks or rocks to remove foreign matter, separate matted fibers, and complete sorting.¹

They either combed or carded the wools, two very different processes for distangling the fibers. To comb, the worker first greased the wool. She either held the lower comb or fixed it to a wooden post, and then pulled the upper comb holding the wool across the lower until it was transferred. Carding, a

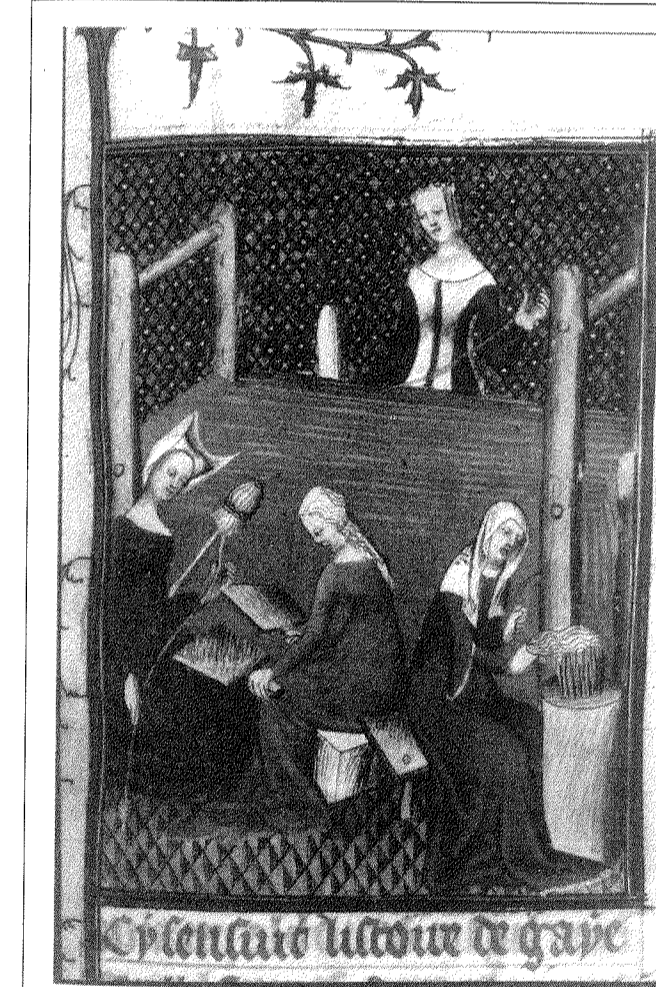


Figure 5. Women preparing wool, an illustration from a fifteenth-century manuscript. The servant on the right is combing wool, using vertical spikes set in a block of wood. In the center a servant cards the wool with a pair of carders. On the left the Lady is spinning wool, drawing it down from the distaff. At the top, a woman is winding the warp yarn in preparation for the loom (Royal Ms. CV. f. 75, by permission of the British Library).

much later technique, was probably introduced in the new cotton industries of Italy and Spain around the eleventh century. Cards, which were used in pairs, were leather implements with fine sharp hooks bent toward the handle (Figures 5 and 6). Carding was advantageous in that it could separate the fibers without removing short fibers, and could blend together a variety of wools, including wools dyed in different colors. Carding was controversial and initially banned in several localities, possibly because, as John Munro suggests, it allowed shorter fibers to be mixed in with longer ones, thereby degrading the quality of luxury broadcloths.²

Spinning, which seems always to have been done by women, involved drawing out the fibers, twisting them together to form a continuous yarn, and winding them onto a spindle. Spinners worked by hand using two instruments. The distaff was a tool that held the raw wool on a forked end and included a lower end for winding the spun yarn (Figure 5). Spinners accomplished the actual spinning with a drop spindle whorl, a wooden disc attached to a rod that served as a flywheel and allowed the spinner to turn it rapidly as it moved toward the ground while she twisted the wool. Around the thirteenth century the spinning wheel was developed (Figure 6). The spinning wheel increased productivity more than threefold. Initially it produced inferior yarn, but yarns improved after the introduction of a flyer with two arms and a separate bobbin that allowed the simultaneous drafting, twisting, and winding on of the yarns. Eventually a mechanism to control the tension and a foot treadle were added, freeing the spinner's hands and allowing her to produce high quality yarns.³

Once the yarn was spun, workers put it on a loom for weaving. They placed the warp yarns first, forming the foundation. After the warp was in



Figure 6. On the left a woman spins using a spinning wheel. On the right a woman cards. From the Luttrell Psalter of 1338 (Ad. Ms. 42130, f. 193, by permission of the British Library).

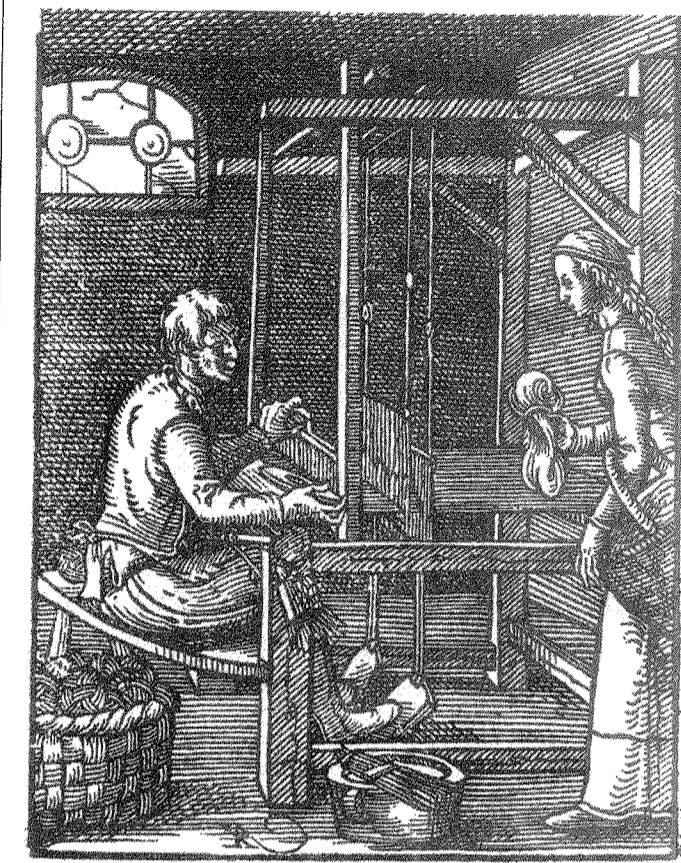


Figure 7. A horizontal treadle loom from *The Book of Trades* by Jost Amman and Hans Sachs. This was originally published in 1568 as *Eygentliche Beschreibung Aller Stände auff Erden* (Exact description of all ranks on Earth).

place, they passed the weft yarn back and forth through the shed or opening made in the warp yarns by a heddle rod. From the fourteenth century, weavers used two different kinds of looms, both invented as alternatives to the vertical warp-weighted loom that had been traditional since antiquity. The first, the horizontal treadle loom (Figure 7), contained warps that were stretched horizontally from front to back. Instead of having shed and heddle rods, the loom was constructed with a heddle harness suspended by pulleys from an upper crossbeam or the ceiling above. Weavers operated the harness by a foot treadle below. The second kind of loom, the horizontal broadloom, allowed the weaving of much wider cloths. Most horizontal looms required two weavers, although a narrow horizontal single-weaver loom also remained in use for weaving smaller woolens and most worsted (wool made from long staple fibers that were combed). The smaller loom was cheaper and easier to build and allowed a single weaver to work without a partner.⁴

After weaving, many woolen and some serge cloths were given to fullers for completion of the clothmaking process. Fulling involved washing and beating. It caused the cloth to shrink, compressing the warp and weft together; forcing the fiber ends to mat; felting the cloth; and making it thicker, denser, and stronger. The fuller first scoured and washed the cloth with "fuller's earth," a clay-like material containing hydrous aluminum silicates combined with other substances such as urine. Next he or his assistants placed the cloth in the fulling vat and stamped on it or beat it to remove the wrinkles and untwist the fibers. He then removed it; greased it with lard; put

it back again into more hot water and soap; and scoured, washed, and rinsed it to remove grease. In the Low Countries, fullers worked by hand up to the sixteenth century and beyond. Elsewhere, however, fulling with a mill became one of the first mechanized industrial processes (Figure 8). The mill included a large two-story building, and often a huge wooden waterwheel, either undershot or overshot. The waterwheel rotated a drum with wooden tappets that alternately lifted two heavy oak trip-hammers one after the other and then released them to drop with great force on the wool cloth in a trough below. Fulling mills had already spread through Europe in the twelfth and thirteenth centuries but became even more widespread after the Black Death, when the cost of labor increased.⁵

After fulling, workers began the final finishing processes. Using fuller's teasels (made from the teasel plant, a thistle-like plant with sharp spikes), they raised the loose fibers of the cloth while it was still wet and cut off the nap with shears. They performed these operations while the wool hung on a tentering frame, which stretched and dried it. They raised the nap of the cloth and sheared it several times on wet as well as dry wool. The mechanization of raising began in fifteenth-century England with the introduction of the water-powered gig mill. In the gig mill, teasels set into a rotating cylinder were dragged across the surface of a moving cloth placed on a revolving belt.

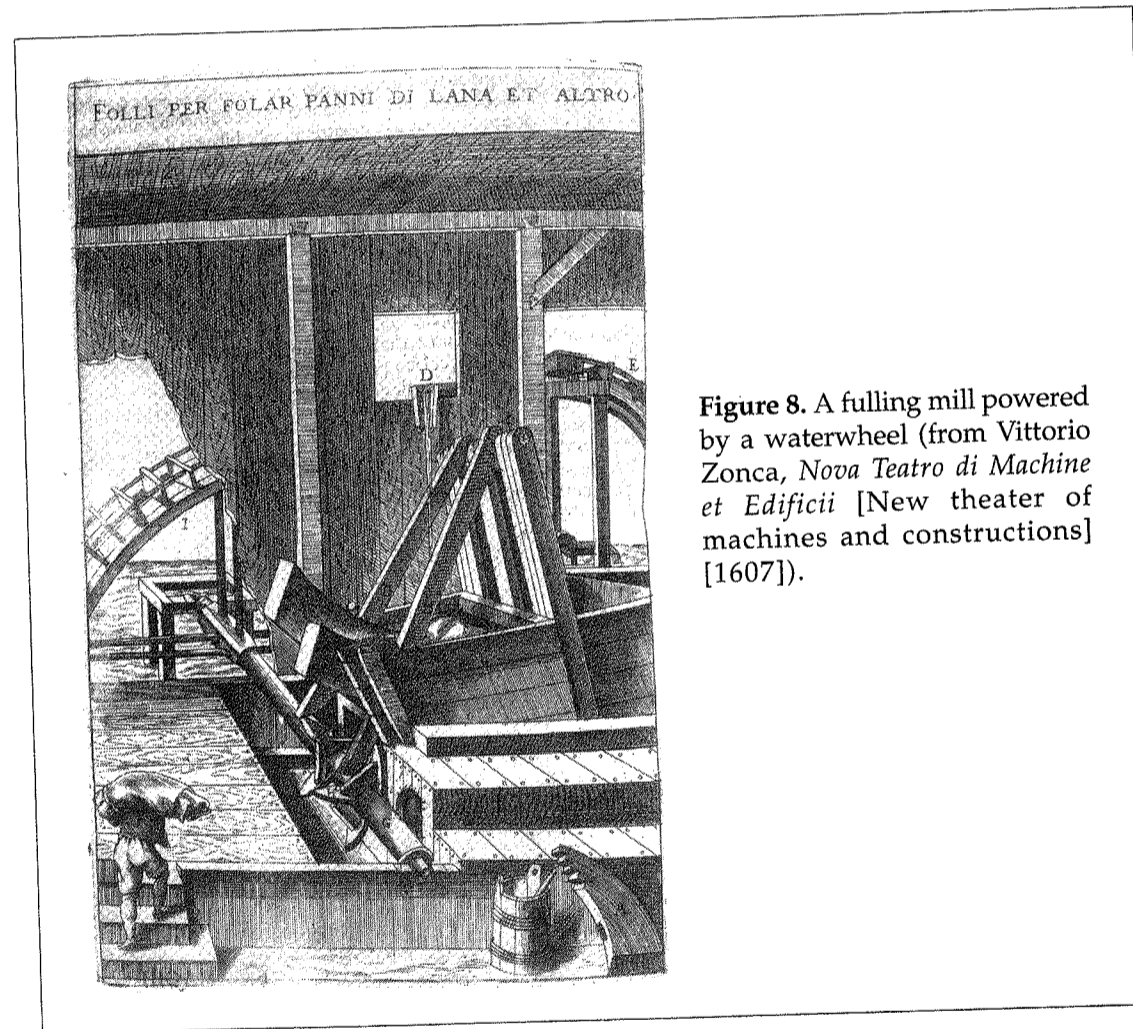


Figure 8. A fulling mill powered by a waterwheel (from Vittorio Zonca, *Nova Teatro di Machine et Edificii* [New theater of machines and constructions] [1607]).

Gig mills were frequently banned for reasons of quality control and perhaps, as Munro suggests, because they led to unemployment. Whether the nap was raised by hand or by a gig mill, shearing completed the process of finishing.⁶

Dyeing was a process for specialists. Dyers could color the wool itself before spinning, they could dye the yarn, or they could dye pieces of woven wool either before or after the final shearing. Dyes were derived from cultivated plants, such as madder for red and woad for blue, and from plants found in meadows, such as weld and woadwaxen for yellow. Imported dyes included kermes, a bright red obtained from an insect of the Mediterranean and Near East and used only for the best wools and for silks. Cloths woven from woad-dyed wools were often dyed again after weaving, with woad serving as the base. For most dyes to be fixed, the cloth had to be dipped in a mordant before dyeing. The most common mordant was alum, mined in Italy, Asia Minor, and the Greek Islands. One advantage of woad was that it did not require a mordant. Mordants made the wool more difficult to work with but were necessary for most other kinds of dye.⁷

In early medieval Europe, the manufacture of textiles was a local, family-based craft with much of the process accomplished by women. By the fourteenth century, wool production had become a predominant component of international trade. It was organized into four major crafts: weaving, fulling, dyeing, and finishing. These crafts used numerous subspecialties such as sorters, beaters, combers, carders, warp spinners, weft spinners, fullers, tenterers, and shearers, to name but a few. Textile workers were usually organized into guilds, and most aspects of the industry were controlled by men, not women. Economic and social changes in the wool industry brought about urban unrest and strife, especially in the fourteenth century, first against the drapers or wool merchants, and then between one part of the craft and another.⁸

The most important entrepreneur of the wool industry was the draper. He, or sometimes she, bought the wool and then had it sorted, beat, washed, and greased by employees or by the wool merchant. Drapers then "put it out" to combers and carders. After collecting it, they distributed the warp and weft wools to hand spinners and wheel spinners, almost all of whom were women working with their own equipment in their own homes. They then collected the yarns for the warpers and winders, also mostly women who usually worked in the draper's workshop or home. Warpers set up the warps on the loom; winders inserted the weft in the shuttles. The draper was a master weaver but also employed other weavers, usually apprentices and journeymen, to work other looms or to assist on the horizontal loom.⁹

The most significant shift in gender roles occurred with the change of loom. The great majority of vertical loom weavers in the early middle ages were female. Especially after the spread of the broadloom, the great majority of weavers (although never all) were male. Male dominance came with larger-scale export-oriented business and guild organization. Although female

weavers became rare, female drapers remained more common, either working as partners with their husbands, as widows carrying on their deceased husband's business, or (less frequently) on their own. Fullers, dyers, and finishers often functioned as independent artisans.¹⁰

Textile workers made wools in many diverse types, weaves, and grades. Among the most important were carded woolens, including kerseys (a twilled woolen fabric) and worsteds (made from long-stapled fibers that were combed, not carded). Fabric styles and trends often changed. For example, in early-fifteenth-century England, broadcloths dominated the industry but gradually lost ground to cheaper and lighter cloths called "new draperies." In addition to wool, other materials were used to make cloth; most important were cotton, linen, and silk—an increasingly important luxury cloth through the sixteenth century. Each material formed the basis for a separate industry, using its own technologies based on the diverse characteristics of the materials themselves.¹¹

SPECIALIZED CRAFTS AND THE TRANSMISSION OF CRAFT KNOWLEDGE

In the centuries between 1300 and 1600 a large number of specialized crafts flourished. Aside from textiles, products ranged from mundane necessities such as pots and pans, harnesses, saddles, everyday glass and ceramic ware, plowshares, benches, and stools to luxury items including fine leather gloves, jewelry and furs, exquisite glassware, silver plates and candlesticks, inlaid wooden chests, and fine majolica ware. The broad range of crafts and manufactures is notable, as is the extensive specialization that developed to carry out this production.

Masters, journeymen, and apprentices practiced such crafts within guild systems as did also workers in households and shops outside the guilds. In such highly specialized crafts as glassmaking and fine ceramics, craft secrecy was the rule. Secrecy involved an attempt to prevent craft processes and recipes from being transmitted to individuals outside of the local guild or locality. The Venetian Senate, for example, demanded that glassworkers not transmit their knowledge of glassmaking outside of Venice. Venetian glass was the finest in Europe and the senate intended that its manufacture be restricted to Venice. The senate also sought to maintain the quality of Venetian glassware, promulgating rules concerning materials and other aspects of the craft to ensure quality control.¹

Craft specialization was determined by raw materials and also by the nature of the final product. For example, leather workers were divided among specialties that dealt with one or more leather products, such as shoes and boots, belts, gloves, saddles, harnesses, sacks, bottles, scabbards, and helmets. Leather is the preserved hide of such animals as sheep, cows, goats, or pigs. Hides consist of three layers: an outer layer of hair, the main skin structure or corium, and a fleshy layer of fat; the corium is made into leather by the process of tanning. Leathermaking was generally divided between those who tanned the leather and those who made leather products.²

Tanners received their hides from butchers and then washed them, often in a local stream or river. They removed the hair by folding the hide and putting it into pits with lime or urine. After scraping the hide, they tanned it in the pit with a vegetable tanning agent, usually oak bark. They prepared the bark by grinding it with a mortar and pestle or in a bark mill and then mixing it with water. The hide remained in the pit with the tanning agent for six months to two years. The tanner then dried the leather and sold it to a currier who converted it into the kinds of leather needed for various objects. The currier wet the leather and softened it by tramping on it or pummeling it. He shaved it to the correct thickness, worked it over with bristles to flatten

and stretch it, and rubbed it with substances containing fish oils and other materials. Lighter leathers for gloves and other soft objects were worked by artisans, distinct from tanners and curriers, who used different processes. In England they were called whittawyers or tawyers. Tawyers used hides other than cattle and treated them with alum and oil rather than oak bark. Specialized artisans who made leather products included shoemakers, bottle makers, glovers (many of whom were women), and saddlers. Saddles, which consisted of a wooden structure (called a tree) covered with leather, were designed to take the weight off the horse's spine. They were made with the cooperation (or sometimes mutual animosity) of leatherworkers and joiners.³

Another highly intricate craft—pottery—produced a variety of vessels, plates, and cups as well as tiles for floors and roofs. The multifarious techniques of pottery-making in Europe and England were strongly influenced by wares that came from the East. For example, Chinese porcelains first arrived in Europe in the fourteenth century and proliferated thereafter, inspiring numerous European attempts at imitation. Pottery-making involved digging the clay and making objects either in molds or on a pottery wheel, drying the objects, and then glazing them. These processes required one or more firings in a kiln. Potters “threw” vessels on pottery wheels, which they turned with the hand or the feet using kick wheels (Figure 9) that left both hands free. To make tiles, they put clay into molds or forms on a flat surface, which they then stacked to dry. They often glazed unfired tiles with lead combined with other materials for color. The addition of copper, for example, produced a green glaze. The fabrication of fine tiles for floors and walls developed particularly in Spain under Moslem influence. In fourteenth- and fifteenth-century England, there is evidence for increased use of floor tiles for manor and town houses and royal buildings. Kilns, which were designed differently for pots and tiles, were fired with coal, wood, or peat.⁴

An important development in pottery during this period involved the emergence of fine majolica ware in Italy. As Richard Goldthwaite describes it, a series of events allowed the craft of Italian majolica to flourish: the importation of tin-glazed pottery from the Islamic world in the eleventh and twelfth centuries; local Italian production of ceramics with lead glazes, then tin glazes with painted and incised decorations; the spread of that production technique; and finally “the elevation of the quality of production to a veritable art form.” The extraordinarily elaborate decorations, as well as the emergence of numerous centers of majolica production and of foreign markets, contributed to the growing ascendancy of Italian ceramics. New glazes, including the development of tin glaze, and new colors were centrally important. Eventually Italian majolica superseded the more conservative majolica production of Spain on the international market.⁵

Glassworkers throughout Europe made numerous kinds of everyday and luxury glassware objects. Glass is an amorphous substance made by firing a mixture of sand and soda or potash. Glassworkers fired their

products in clay crucibles that had to sustain temperatures of 1,200°C. They added other substances to the basic glass mixture for coloring. Glassmaking involved at least two stages of firing: fritting raw materials and then melting. In fritting, workers fired the mixed materials in a low-temperature furnace while raking them. This process eliminated gases and assisted the process of melting, which was then carried out in a higher temperature furnace, one that consumed huge quantities of wood.⁶

Glass products included vessels of various kinds, distillation equipment for alchemical and medicinal purposes, and windows. Venetian glassworkers made the finest luxury glassware, and attempted to guard the secrets of their craft. Across Europe glassmakers fabricated glass windows for churches and other buildings. Using white glass from glassmakers, glaziers made it into stained glass windows. The glazier made a careful cartoon, or pattern, for the design. Then he painted on the glass pigments and fired the pieces in an annealing furnace. He joined the colored pieces together with lead. The entire window was completed before it was inserted into the window opening.⁷

For most crafts, the transmission of craft knowledge occurred predominantly but not exclusively through apprenticeship systems. Yet journeymen who worked for day wages tended to be quite mobile, carrying their craft knowledge with them and transmitting it to others in new places. Eliyahu



Figure 9. A potter makes pots using a kick wheel. In the background, workers dig clay (from Jost Amman and Hans Sachs, *Book of Trades*).

Astor emphasizes the importance of the migration of workers in transferring craft knowledge across borders. Guild regulations and artisanal competition encouraging secrecy were countered by a newly developing system of patents. Artisans frequently obtained patents or limited monopolies for bringing novel inventions or craft processes into a particular locale, setting up shop, and manufacturing the product (often in exchange for training apprentices). Venetian glassworkers, for example, obtained patents in many parts of Europe despite laws forbidding them to take their craft outside of Venice. Both the practice of craft secrecy and the transmission of craft knowledge to new locales by the lure of patents were common practices especially in the more specialized crafts. Secrecy and patents both point to new attitudes of intellectual property—that is, the view that inventions and craft processes are separable from labor and from objects, and represent intangible property belonging to the artisan, the guild, or the government.⁸

PAINTING AND SCULPTURE

The craft product from the Renaissance most widely known in the modern world is painting—from frescos to painted wooden altarpieces to small panel paintings. The names of such painters as Leonardo da Vinci, Raphael, and Michelangelo are almost universally recognized, whereas hundreds more painters are known to scholars and others. Paintings are the focus of innumerable courses as well as pilgrimages to galleries, churches, and other sites. Most painting was based in workshop practice where the master instructed and was assisted by apprentices and journeymen. Painting involved a foundation of technological practices that could remain the same despite significant changes in style.

Anabel Thomas, through a detailed examination of an early fifteenth-century manual on painting by Cennino Cennini, explicates some of the material and technological basis of the craft. She takes as an example a painted wooden altarpiece. Much had to be done before the paint was actually applied. First the gesso, which covered the surface, had to be made. The painter cooked old bones such as chicken bones in a fire until they turned white and then he ground them into a powder. Different grades of gesso included *gesso grosso* for the main covering and *gesso sottile* for the surface where more detailed work would be carried out. For the *gesso sottile* the painter purified the powder in water for several weeks, then drained the liquid and formed loaves, which he set out to dry. After that, he sliced the loaves thinly, mixed the pieces with size (a type of glue), and cooked them without boiling.¹

The various colors for the painting also required extensive preparation, although some pigments could be purchased from apothecaries or spice merchants. Colors required grinding and grading, an activity that often took many days. Painters mixed the pigment with water and with treated glue. They also made drawing materials by hand—charcoal by slowly roasting twigs on the embers of a fire, pens from the quills of goose feathers. They made brushes by cooking miniver (ermine) tails and using the hairs. They used hog bristles for less delicate brushes to lay the gesso. Making tempera paints with eggs, artisans either kept chickens themselves or bought eggs from a poulterer. They made glue by boiling goat feet and other parts.²

A woodworker carved the altarpiece itself. After the painter received it, he prepared it further by planing it down to make it flat and remove any grease. He filled flaws and cracks with sawdust and glue, beat down nail ends, and covered rough areas with tin foil. Covering the whole surface with animal glue, he laid on strips of old linen cloth, and smoothed and dried them. Finally the altarpiece was ready to receive the first layer of gesso. After the surface was prepared, the artist would create the design for the painting

on gesso tablets, wax tablets, or tinted paper. Only then would he and his assistants be ready to begin laying the design on the surface and painting it.³

In the fourteenth century, paint usually consisted of tempera, that is, egg yolk or the whole egg mixed with a paste of pigment and water. Its qualities influenced painting techniques. Tempera dries first by the evaporation of water, after which the egg protein eventually hardens into a waterproof surface. Since volume is lost with drying, the paint must be applied thinly to the surface to avoid cracking and surface flaking. Painters began to use oil paint after the mid-thirteenth century, mixing linseed or sometimes walnut oil with their pigments. This practice gradually spread from northern Europe to the south. Unlike tempera, oil paint could be applied thickly. It makes pigments more transparent, and, because it dries slowly, it allows blending and soft modeling. It is particularly well-suited to canvas rather than wooden panels. In fifteenth-century Venice, oil painting on canvas became a flourishing practice that spread to other parts of Europe. Both the kind of paint and the surface upon which it was applied affected painting style in profound ways.⁴

Fresco painting was a technique used for large-scale wall painting. The painter applied wet lime plaster to the wall and then put on pigments that had been dissolved in water. As they dried, the pigments became an integral part of the wall. Before a wall could be painted, it had to be cleaned and dampened and a layer of coarse plaster applied—a procedure that could be completed several years before the fresco was begun. Artisans carefully prepared the top layer of lime plaster that would hold the pigment. The plaster consisted of slaked lime and a filler such as sand, ground marble, or pozzolana (a volcanic clay). The lime was obtained by firing calcareous rocks to about 900°C, adding water to the resulting quicklime, and maturing it in vats, sometimes for several years. The painter usually drew the design for the painting on a cartoon. On a daily basis, the painter applied wet plaster to the wall, applied guidelines to it from the cartoon, and then put on the pigment. The best time for painting was two or three hours after laying down the plaster. As it dried, painting became more difficult and finally had to cease. The painter removed unpainted plaster and began the process again the following day.⁵

A significant development for painting, drawing, and relief sculpture was the discovery of artist's perspective by Filippo Brunelleschi and others in Florence in the 1420s. The Florentine humanist, Leon Battista Alberti, first explained in writing a version of perspective in the 1430s. Artist's perspective involved a method of geometric projection in which the illusion of three-dimensional space could be created on a flat surface. Perspective became fundamentally important to Renaissance painting, as it also facilitated the drawing of complex machines and interior and exterior spaces. Perspective, foreshortening, and other techniques intensively developed in the fifteenth century, encouraged drawing and painting from the observation of nature. Plants and animals, human bodies, and eventually human anatomy, rocks,

streams, and natural settings all came to be rendered with acute observational skill. For some, such as Leonardo da Vinci, the observation and depiction of nature came to be closely tied to the investigation of nature. Thus Leonardo studied human anatomy, water, flying, and the motion of machines by means of careful observation and visual depiction.⁶

Although the relative merits of painting versus sculpture were hotly debated in the fifteenth and sixteenth centuries, both practices flourished. Sculpture, the shaping of three-dimensional objects, or scenes in relief, could be accomplished by cutting hard materials including stone, ivory, or wood; by modeling clay; or by casting metal such as bronze. In carved sculpture, techniques were dependent on the material used. Stones for carving vary greatly in their hardness and other physical characteristics. Sculptors frequently utilized marble, a kind of hard limestone recrystallized by heat or pressure. Marble comes in many colors from gleaming white to green, pink, grey, and black, colors caused by impurities. Other stones used less often for sculpture during this period included the very hard granite, and porphyry, a relatively rare, extremely hard, usually red-purple stone.⁷

In her study of sixteenth-century Florentine porphyry sculpture, Suzanne Butters emphasizes the close relationship of the sculptor who needed a wide range of cutting tools and the blacksmith who made such tools. Many sculptors fabricated their own tools as well. The tools of stoneworkers included "mallets, hammers, axes, points or punches, chisels (notched and flat), drills, saws, files and rasps," as well as "compasses, squares, rulers, templates, tongs and pliers." Sculptors' tools tended to have a short life due to intensive use. Numerous variations of tools were developed for specific kinds of stone and particular tasks. In the Florentine court of Duke Cosimo I de' Medici, an important goal came to be the fabrication and tempering of a steel tool that was hard enough to make large porphyry statues.⁸ Butters's account underscores the symbolic value of certain kinds of materials such as porphyry (signifying royalty and power) and the technological problems that had to be solved before such materials could be used in desired ways.

ARCHITECTURE AND BUILDING CONSTRUCTION

The cities of both northern Europe and the Mediterranean region undertook large-scale building projects during this period, often motivated by a combination of civic pride, religious devotion, and family honor. From the mid-twelfth century, magnificent Gothic cathedrals began to be constructed, first in the great cloth towns of northern Europe and then in other cities and towns. Popular convention associates the Middle Ages with Gothic cathedrals, and the Renaissance with the classical architecture first developed by the architect/engineer Filippo Brunelleschi and others in early fifteenth-century Florence. But this is an oversimplification, especially considering that Gothic cathedrals were built through the sixteenth century and even after. Gothic and classical are very general terms better used with reference to two different architectural styles than as markers for two different historical eras.

Gothic cathedrals are immense, complex buildings that incorporate at least three structures (each developed separately within prior traditions of building) that function together. They are the pointed arch, the rib- or cross rib-vault that derives from that arch, and the flying buttress (**Figure 10**). The flying buttresses support the walls of the nave from the outside, allowing

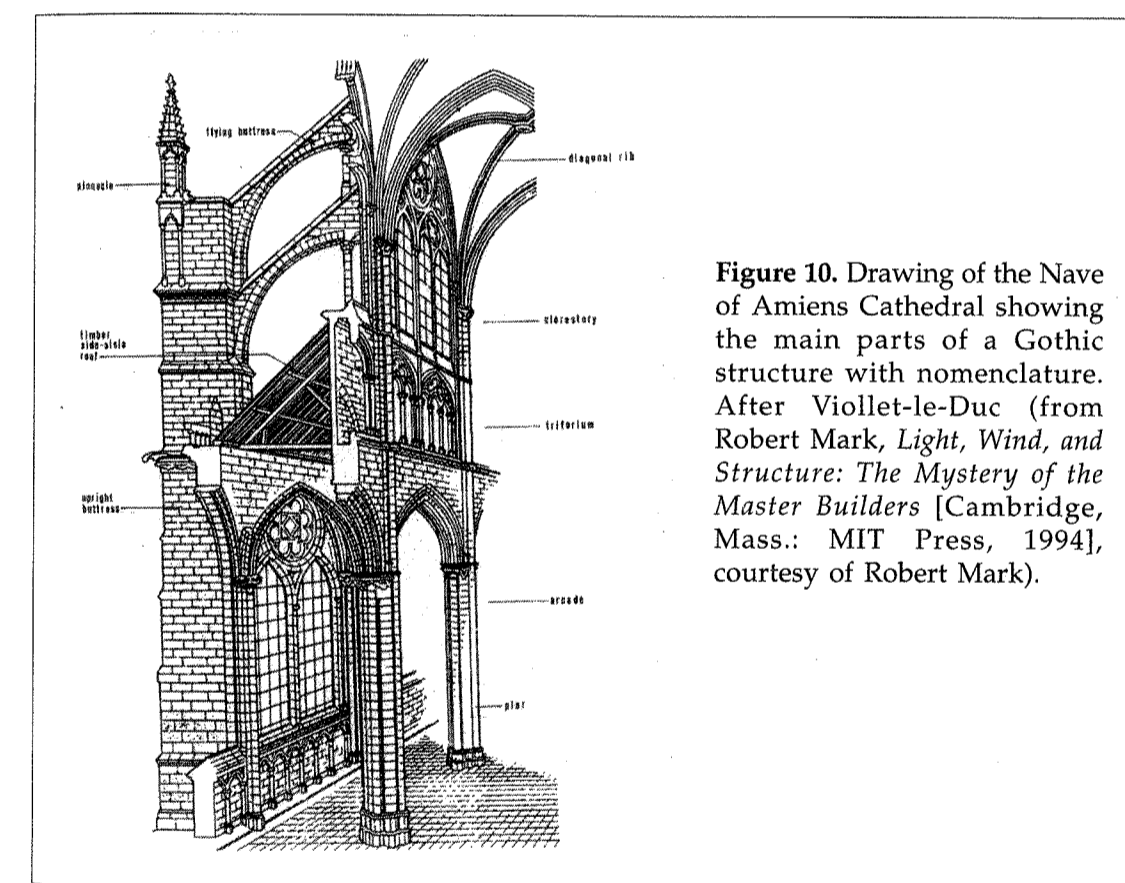


Figure 10. Drawing of the Nave of Amiens Cathedral showing the main parts of a Gothic structure with nomenclature. After Viollet-le-Duc (from Robert Mark, *Light, Wind, and Structure: The Mystery of the Master Builders* [Cambridge, Mass.: MIT Press, 1994], courtesy of Robert Mark).

them to be constructed high and relatively thin. Walls were filled with beautiful stained glass windows, letting in a flood of light that medieval theology understood to represent divine illumination.¹

Gothic cathedrals were built by teams of masons and carpenters, along with journeymen and apprentices, headed by skilled master masons. They worked empirically, using other buildings as approximate designs and carefully observing cracking, an important sign of weakness in the structure. Robert Mark and his colleagues have studied cathedrals using the modern engineering techniques of photoelastic modeling; they created small epoxy plastic models of the cathedrals and then tested them under load conditions similar to those of the actual buildings. From these studies have emerged a greater understanding of how the cathedrals work as structures. Mark has discovered, for example, that elements such as the great pinnacles on the buttresses of the cathedrals at Reims and Amiens were not purely decorative as had previously been believed, but added structural stability to the buttresses by adding "compressive force to the stones below it, helping to consolidate them . . . and prevent their lateral sliding, or shearing, under the action of the horizontal component of thrust from the flying buttress."²

The very different style of classical architecture, inspired by ancient motifs, was developed in the early fifteenth century. Here, the work of the architect/engineer Filippo Brunelleschi is fundamentally important.

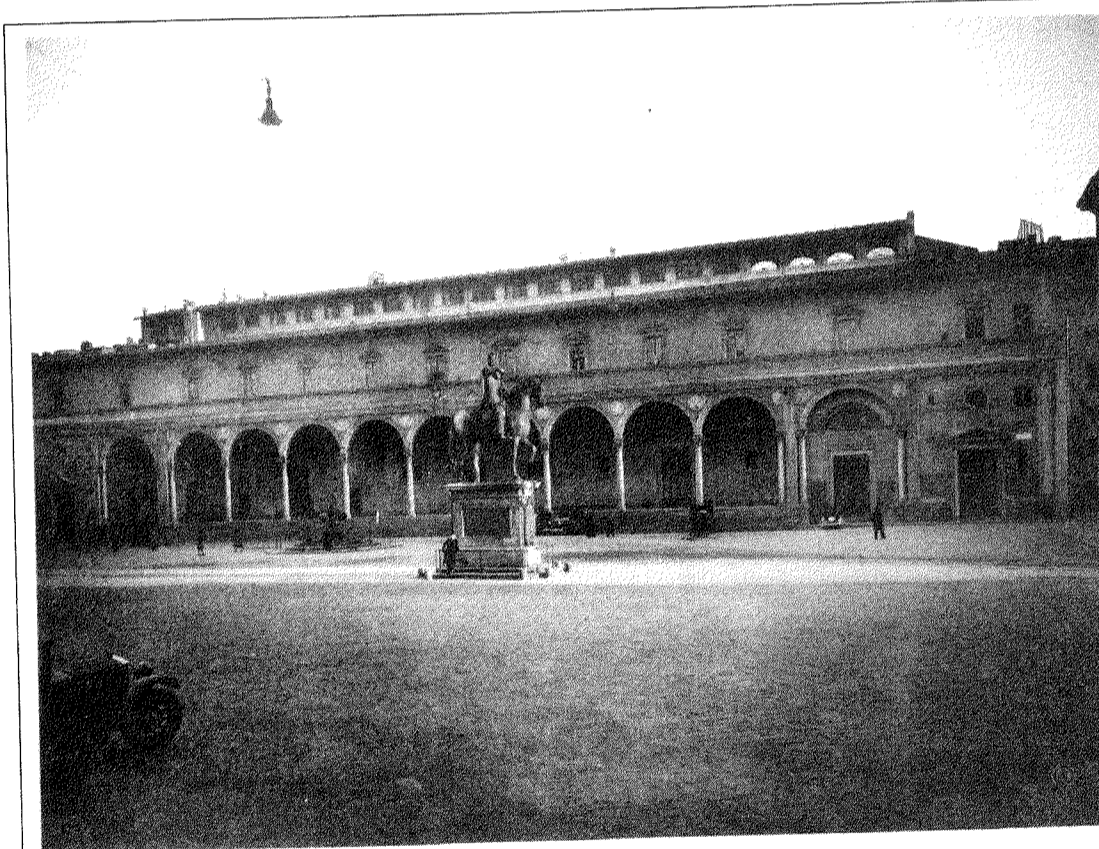


Figure 11. The *Ospedale degli Innocenti* in Florence was the first building designed in the classical style to be built by Filippo Brunelleschi. The building was begun in 1419 and completed in the mid-fifteenth century (credit: Alinari/Art Resource, NY).



Figure 12. The Florentine Cathedral with its famous dome designed by Brunelleschi dominates the city of Florence to this day. The dome contains outer and inner shells, the walls of which were built up in a herringbone pattern (credit: Alinari/Art Resource, NY).

Brunelleschi's new style, first in evidence in the *Ospedale degli innocenti* in Florence, involved a design in which each element of the building was mathematically proportional to every other element (**Figure 11**). This classical architecture underwent a broad development throughout Europe, its principles applied to structures as diverse as churches, loggias, great public buildings, and the palaces of merchants, princes, and emperors.³

Yet the structure for which Brunelleschi was most famous is not a classically styled building, but rather the great dome of the Cathedral of Florence (**Figure 12**). Constructed between 1420 and 1436, it is one of the largest masonry domes ever built, spanning the octagonal drum of the cathedral over a space of about 140 feet, or 42 meters. The space was too large to use traditional timber armature (a wooden structure upon which a dome is supported while being constructed). The city of Florence displayed notable confidence in building the massive cathedral up to the dome without knowing how to cover it. Brunelleschi's solution, finally adopted after much discussion and argument, involved three features. First, the stresses of the dome were distributed on eight major and sixteen lesser vertical ribs that joined at the top. Second, the dome was built as a double-shelled structure, inner and outer, a construction technique followed by many later architects. And third, the brickwork of the two shells was built up in a herringbone pattern that enabled them to be self-supporting during construction. Brunelleschi also designed scaffolding and innovative hoisting machines to carry out the work.

He closely supervised the construction of the dome, acting far more like a general contractor than would a modern-day architect.⁴

The building trades flourished in fifteenth- and sixteenth-century Europe, motivated by the desire for more spacious and comfortable living quarters, by a growing culture of consumerism, and by a new ethos involving conspicuous consumption by elites. In England, such trades expanded greatly in the sixteenth century as commercial farmers and landowners enlarged and improved their houses. Country farmhouses became more comfortable as they acquired second stories, staircases, glazed windows, and exterior chimneys. Numerous parish churches and other buildings were constructed and renovated in Elizabethan England. Elizabethans created a consumer society as they increasingly purchased household furnishings and objects of various kinds.⁵

The boom in construction fueled the trades that provided materials, such as bricks, stone, lime for mortar, and timber. Brickmaking was an important industry that involved digging clay, putting it into molds, and firing it in kilns. Kilns were also used to produce lime from limestone, an essential ingredient of mortar. Masonry construction, as David Parsons succinctly summarizes it, involved numerous skilled and unskilled tasks. First the stone was quarried and roughly finished, and then hauled to the building site. Limestone or chalk was dug for burning quicklime, the active ingredient of mortar; sand was dug to provide its bulk aggregate. Timber was felled and cut for roofing and flooring, as well as for scaffolding and centering for arches and vaults. Construction involved first the laying-out of the building, and then digging foundations, which usually consisted of rubble and broken brick in a mortar matrix, or sometimes only pebbles bound in clay. Then masons began building the walls with stone, which they usually finished at the building site. As the walls went up, scaffolding was built, as were hoists and cranes to lift the materials to a working platform.⁶

Architecture and building construction entailed the activities of numerous skilled craftsmen. Yet architecture also involved a cultural movement focused at first on the ancient architectural treatise, *De architectura*, of the Roman architect Vitruvius (fl. 40s–20s B.C.E.). Vitruvius had suggested that architecture should include both *fabrica* and *ratiocinatio*, construction and reasoning. In the fifteenth and sixteenth centuries, the Vitruvian value of the unity of theory and practice was noted and developed further in numerous architectural writings published not only in Italy, but also in France, Germany, Spain, and elsewhere. Translations of *De architectura* and detailed commentaries on it, as well as independent treatises on architecture, proliferated in these centuries.⁷

Enormously influential was Leon Battista Alberti's Latin treatise on architecture, *De re aedificatoria*, completed around 1450. Yet other treatises and commentaries were written by practitioners such as Antonio Averlino (known as Filarete), an architect who was trained as a goldsmith and who dedicated his treatise (1469) on the ideal city of Sforzinda to the ruler of Milan, Francesco

Sforza. Authors of architectural treatises and commentaries discussed Vitruvius, ancient ruins, and the design of ancient and contemporary buildings. Both practitioners and university-educated humanists like Alberti wrote treatises and Vitruvian commentaries. Architecture came to be a discipline through which learned men and skilled practitioners communicated with one another.⁸

MINING AND METALLURGY

Mining and ore processing in the fourteenth century were traditional activities in some areas of central Europe and England—small-scale, local operations, often carried out part time by individuals otherwise occupied with agriculture. Local entrepreneurs mined gold, silver, copper, and iron in central Europe and elsewhere. Especially in Devon and Cornwall in southwest England, they mined tin, used for pewter and bell casting, and lead, used for roofing materials. As the population of Europe gradually recovered from the devastation of the Black Death in the first half of the fifteenth century, the supply of metals for coins and for guns did not meet demand. The result was a central European mine boom that extended from about 1460 to 1550, with output of silver, copper, and other metals increasing as much as fivefold. This greater productivity was the result of deeper mines that required large-scale capital investments; wage labor; and new, large-scale excavation and ore-processing equipment.¹

The new capitalist mining operations, financed by the princes and patrician bankers of central Europe, were mechanized to a significant extent. The detailed, illustrated sixteenth-century treatises on mining and ore processing by Vannoccio Biringuccio (1540), Georg Agricola (1556), and Lazarus Ercker (1574) show deep mine shafts; many kinds of pumps and other water removal equipment, often powered by huge waterwheels (**Figure 13**); furnaces and other ore-processing apparatus; and ventilating machines made with revolving fans and bellows. The treatises describe equipment for crushing ore, and sieving and roasting apparatus driven by waterwheels.²

Technical developments in metallurgy occurred relative to specific kinds of metals. In the fourteenth century, wrought iron production involved bloomery furnaces. In this process metal workers crushed and washed the iron ores. Then they roasted the ore with green timber and quenched it with water. They mixed the ores with charcoal in a furnace and covered them with fuel, directing bellows to the center of the hearth. The resulting product is called the bloom. They purified and consolidated the bloom by a process of hammering, further heating, and hammering again to remove the slag. In the fifteenth century some bloomery furnace bellows were powered with waterwheels, which allowed an increase in the size of the bloom to over 100 kilograms. Smiths worked the cut-up pieces of this bloom by hammering on a second hearth.³

The blast furnace appeared in Europe in the fifteenth century, making possible the regular production of cast iron. Constructed by raising the height of the furnace and increasing the force of the blast, the new furnaces achieved temperatures sufficiently high so that liquid iron could flow out to be cast as

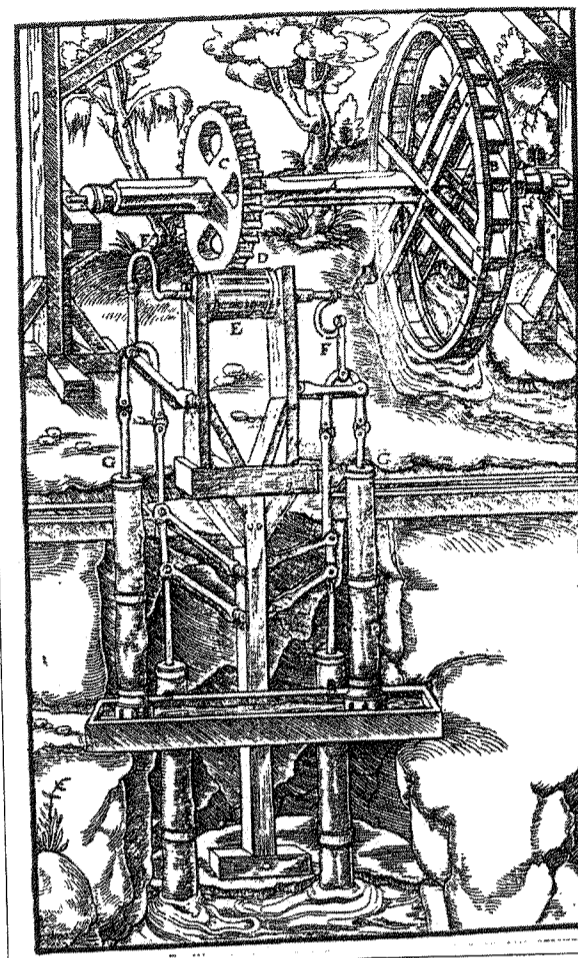


Figure 13. Suction pumps powered by an overshot waterwheel drain a mine (from Georg Agricola, *De re metallica* [1556], trans. Hoover and Hoover, 189).

molten "pigs." Blast furnaces were more capital-intensive and had to operate continuously (in contrast to the intermittent operation of the bloomery furnace) for effective production. Iron production in the sixteenth century included both bloomery furnaces producing wrought iron and blast furnaces producing cast iron. Among other things, cast iron was used for cannon balls, pots and pans, and, after the 1540s, guns.⁴

For such nonferrous metals as silver, copper, and lead, metalworkers often purified ores by roasting on open piles or in open-shaft furnaces. Then the ores were smelted, a process of firing that involves a chemical reaction between the fuel and the ore. These metals were usually smelted in blast furnaces, built of stone with renewable linings of clay. The crucible that held the metal was lined with *brasque*, a paste of charcoal tempered with clay. Smelter furnaces reacted ores in a reducing atmosphere to strip them of their chemical bonds and render them into a pure state.⁵

The changing technologies of mining and ore processing, and the transformation of mining into large-scale capitalist enterprises, affected labor in particular ways. For example, Susan Karant-Nunn has investigated women's work around the mines of the silver-rich Erzgebirge mountain in central Germany. In the fourteenth and early fifteenth centuries when mining was small scale, veins near the surface often were worked by families—husband, wife, and any children old enough to help. As mining changed to deep shaft,

capital-intensive enterprises, the various tasks carried out by men became more specialized and women's role diminished. Yet pictorial evidence and legal documents both indicate that women regularly worked in some areas of ore processing, such as washing and sorting (see Figure 14).⁶

Weekly accounts recording the Saturday payout to all workers show that women were chiefly part-time breakers and launderers of the ore, and that they worked alongside men and boys for the same (very low) wages. In other functions, they are found less often. In one smelting hut, one or more unnamed women were recorded as mixing coal dust with clay to make briquets for use in separating copper and silver. For this skilled work they earned twice as much as miners. There is also evidence that poor women, often widows or wives of sick miners, went from shaft to shaft seeking work—carrying iron tools, rope, and other equipment. The wife of the hut keeper, living with her family at the shaft itself, enjoyed an advantageous position. Often she sorted ores, undertook other tasks, and called other women to help when needed. The fortunes of both female and male miners and metalworkers declined when the central European mine boom ended around 1550. Depleted mines combined with the price inflation brought about by the flood of precious metals from the New World (which effectively cheapened the price of the metals) brought an end to easy profits in European mining.⁷

Metallurgical craftwork with processed metals was diverse and highly specialized. Copper alloys were processed and used to make many objects, from candlesticks and pots to bells, guns, and large equestrian statues. Although in modern usage bronze is mainly an alloy of copper and tin, and brass is an alloy of copper and zinc, Claude Blair and John Blair point out that earlier alloys and their terminology were far more variable. A common copper alloy for casting, for example, consisted of a mixture of copper, zinc,



Figure 14. The women in the foreground are sieving charcoal to prepare it for combining with clay to make the hearth and forehearth of a furnace for smelting non-ferrous metals (from Georg Agricola, *De re metallica* [1556], trans. Hoover and Hoover, 374).

tin, and lead, and in England was called *latten*. Smiths worked copper alloys in two ways, by forging with a hammer and by casting. In forging, they cut the sheet metal into the appropriate pattern for the object to be made, annealed (heated and slowly cooled) it to soften it, and then hammered it cold on anvils.⁸

Casting copper alloys required melting the metal and then pouring it into a mold. The molds were made from stone, clay, or metal and could be made in one piece or several. Objects were usually cast using the lost wax process. Here, the object to be fabricated was modeled in wax, if necessary over a clay core, and was then covered with clay, leaving a pour hole. It was then heated so that the clay would harden and the wax melt out. Molten metal was then poured in and, after it hardened, the clay was broken away. A later method in use by the fifteenth century involved sand casting, in which the mold was made of compacted sand in molding boxes around a form of wood. Once cast, objects could be pieced together if necessary, lathe-turned, filed, and then polished.⁹

Bells, guns, and statues were the the largest objects to be cast. Each of these required specialized procedures, especially with regard to constructing the molds. The first detailed account of casting guns is found in Biringuccio's *Pyrotechnia*. The fabrication of equestrian statues was undertaken in various localities from the early fifteenth century, and at times guns and statues became conflicting projects. For example, in the 1490s, Leonardo da Vinci began work on the large bronze-cast equestrian statue of Francesco Sforza in Milan. Wanting to cast the statue in one piece (unprecedented for such a large project), Leonardo experimented with casting methods, using his knowledge of casting guns, and constructed molds and a model. However, the times were not propitious. At the breakdown of the alliance between France and Milan, with French troops approaching the city, Ludovico Sforza, the ruler of Milan, sent some 158,700 pounds of bronze reserved for the statue to Ferrara to make guns. When they arrived in Milan, French soldiers destroyed Leonardo's model by using it for target practice.¹⁰

Goldsmiths worked gold and silver with forge and hammer or by casting. They usually forged vessels and dishes, and cast jewelry. To forge, they hammered an ingot into a sheet, cut it to size and shaped it with a hammer. Annealing (heating and then cooling the metal) prevented hardening. They further treated the surface by planishing (smoothing) with special hammers and then polishing. In casting, they used crucibles for melting and poured the liquid metal into piece molds or cast it by the lost-wax process. They attached precious stones to gold and silver with a solder, an alloy often containing lead.¹¹

Smiths produced decorations on precious metals in various ways. They used dies to achieve repetitive motifs by placing a sheet of metal to be decorated on the die, providing a protective covering, and hitting it with a hammer. The motifs could then be cut out and attached directly to the silver. Embossing involved working the metal from the back with a hammer and

punch, while chasing the metal required working from the front. Engraving required a fine tool to cut out thin lines. Other methods included enameling, that is, firing on powdered glass. Smiths often obtained gold for gilding from gold coins, which they hammered repeatedly between sheets of vellum. They used gold leaf for decorating manuscript books, panel paintings, and walls. They laid the leaf on a surface that usually had been prepared with gesso.¹²

The minting of coins was a specialty unto itself. Numerous princes throughout Europe who minted their own specie employed assayers and minters. Assaying to determine the amount of gold or silver in any particular coin or batch of metal was a particularly important part of the craft of minting. Minters fabricated coins by stamping a sheet of metal between an upper and a lower die. The coinage of a realm suggested the power and authority of the prince. That so many princes minted their own coins underlay the widespread confusion of specie in this period.¹³

ARMAMENTS, GUNPOWDER, AND THE "MILITARY REVOLUTION"

Between the fourteenth century and the early seventeenth, warfare changed as a result of technological, organizational, and societal factors. Perhaps the best known of these complex changes involves gunpowder artillery. Bert S. Hall demonstrates that gunpowder did not result in overnight transformations, but developed slowly and is best seen in relation to other kinds of weaponry and aspects of warfare. Gunpowder weapons appeared in Europe from the 1320s, but they did not become central to the conduct of war until the sixteenth century. In the fourteenth century, standard missile-shooting weapons were the crossbow, the longbow, and the trebuchet. The crossbow had a mechanical loading mechanism. The longbow was drawn to the ear instead of the chest, and shot a longer arrow that went farther than the traditional arrow and also had much greater penetrating power at close range. Its disadvantage was that its use required training from childhood. The counterweight trebuchet was a large artillery machine that discharged stone or lead balls by means of a counterweight mechanism. Winches pulled the longer arm down, raising the counterweight to a certain height. When the counterweight was released by a trigger, its sudden fall hurled the missile in the sling toward the target (see **Figure 15**). Captains used the trebuchet, which was highly efficient against fortifications, until the end of the fifteenth century.¹

Armies of pikemen could serve as an alternative to missiles. Pikes were elongated spears held by tightly massed and disciplined soldiers who moved in formation, and who were trained to face the charges of cavalry without breaking. The Swiss were the most renowned practitioners of pike warfare in the fifteenth century. In general, late medieval warfare was in a state of change in which traditional means, such as those involving heavily armed knights, were deployed against new military forms such as pikemen. Often, military leaders combined new tactics with new combinations of weaponry. Yet, as Hall points out, rulers did not have a full range of choices in deploying an army. Only the English could deploy longbowmen, since only English social and cultural conditions produced a sufficient number of men with the necessary extensive training. The Swiss and the Flemish, having small countries with cohesive populations, were able to organize and train armies of pikemen, but the French could not.²

Gunpowder entered slowly into this complex military arena. A product of Chinese alchemical experiment, it consists of a combination of saltpeter, sulfur, and charcoal. Gunners first deployed gunpowder weapons in European warfare between 1325 and 1425. During this period they were heavy,

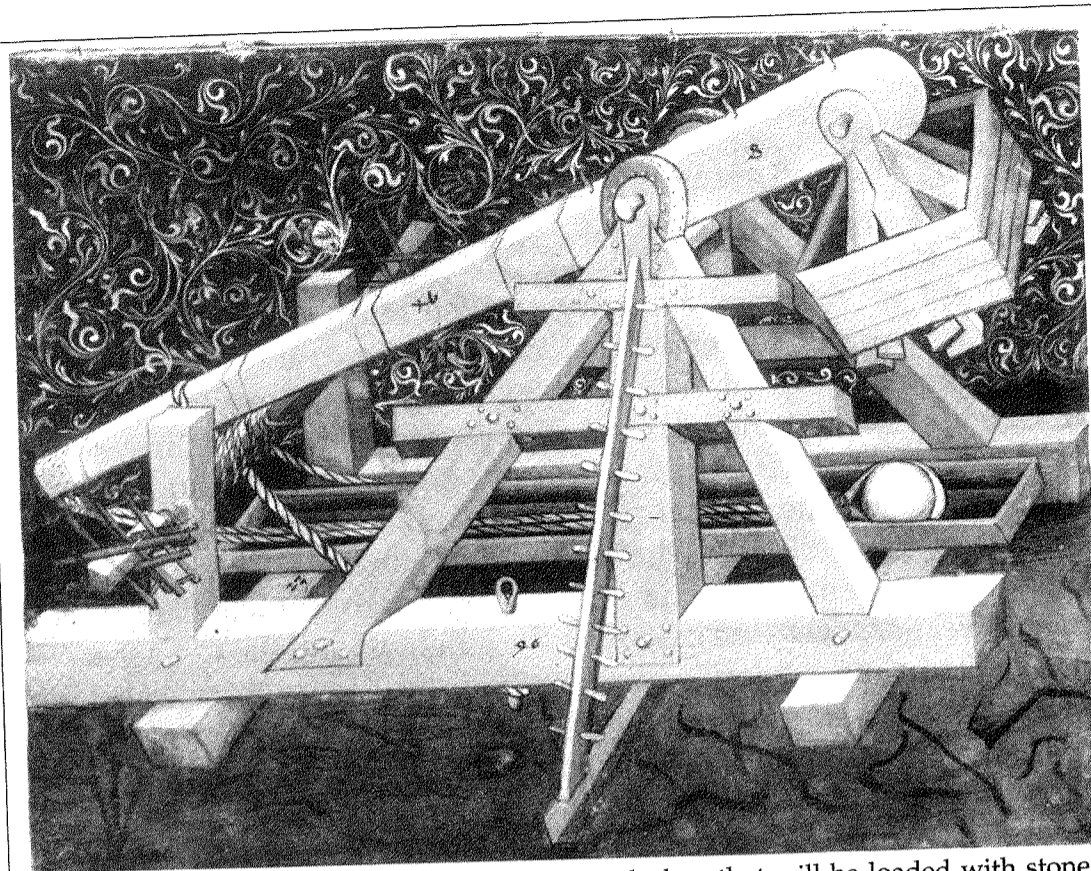


Figure 15. A counterweight trebuchet. The weight box that will be loaded with stones or other heavy weights is at the upper right. The trebuchet has a long sling that rests on a beam. The pouch of the sling holds the shot. At the far left is a winch with winch rope wrapped around it, used to pull up the weight box. When the engine is fired, the weight box falls to the ground, the beam swings up, the sling pulls the shot up and flings it with great force (from Conrad Kyeser, *Bellifortis*, Cod. phil. 63. Courtesy of the Niedersächsische Staats- und Universitätsbibliothek, Göttingen).

inaccurate, and had a slow rate of fire, making them inferior to the longbow and the crossbow. A major advance in gunpowder manufacture occurred during the fifteenth century with the development of corning or granulating the powder. After some years of experimentation in which various kinds of artillery were designed and tried, gradually, the single-piece muzzle-loading cannon came to dominate. Small guns included the arquebus and the musket for infantry, and later the handheld pistol.³

As gunpowder artillery increasingly came into use, traditional medieval fortifications and city walls were found to be inadequate; their tall, flat surfaces turned out to be perfect targets for artillery, a shortcoming that became shockingly evident during the French invasions of Italy in the 1490s. Soon modifications to fortification developed in response to the new weapons. Earthworks, which were rather inexpensive, doubled the effectiveness of medieval curtain walls. Eventually the polygonal bastion fort was developed in the late fifteenth and early sixteenth centuries. Its triangulated surface and raised gun platforms, ditches, detached forts (ravelins), and artificial slopes together offered far more effective defense against gunpowder artillery than had medieval fortifications and town walls (see **Figure 16**).⁴

The development of gunpowder artillery and bastion fortification comprise only some of the elements involved in the debate concerning a "military revolution" in the sixteenth century and beyond. Michael Roberts, a historian of early modern Sweden, first used the term in 1955, referring to developments in Swedish armies during the Thirty Years War (1618–48). Geoffrey Parker considerably broadened the meaning of the term to refer to radical changes in warfare in the sixteenth century that marked the difference between the medieval and modern worlds. For Parker, the changes involved gunpowder, artillery, the development of bastion fortification, and then a huge increase in the size of armies to besiege the new fortifications effectively, as well as changes in the arming of ships at sea. Parker's thesis of a military revolution continues to be vigorously debated, with some scholars suggesting that it presents an oversimplified and unduly accelerated picture of military change.⁵

Warfare involved far more than the complex issues of technological change. Military forces, whether consisting of small marauding mercenary bands or the increasingly large armies, could exert a devastating effect on villages and fields in the countryside, even without the occasional deliberate burning of villages and crops to destroy the supply sources of enemy forces. An army might be thought of as a traveling city. It was made up of men, women, and children. Women sometimes fought and occasionally led armies—Joan of Arc being the most famous female general. Most women served not as combatants, but in the huge supply train that constituted an

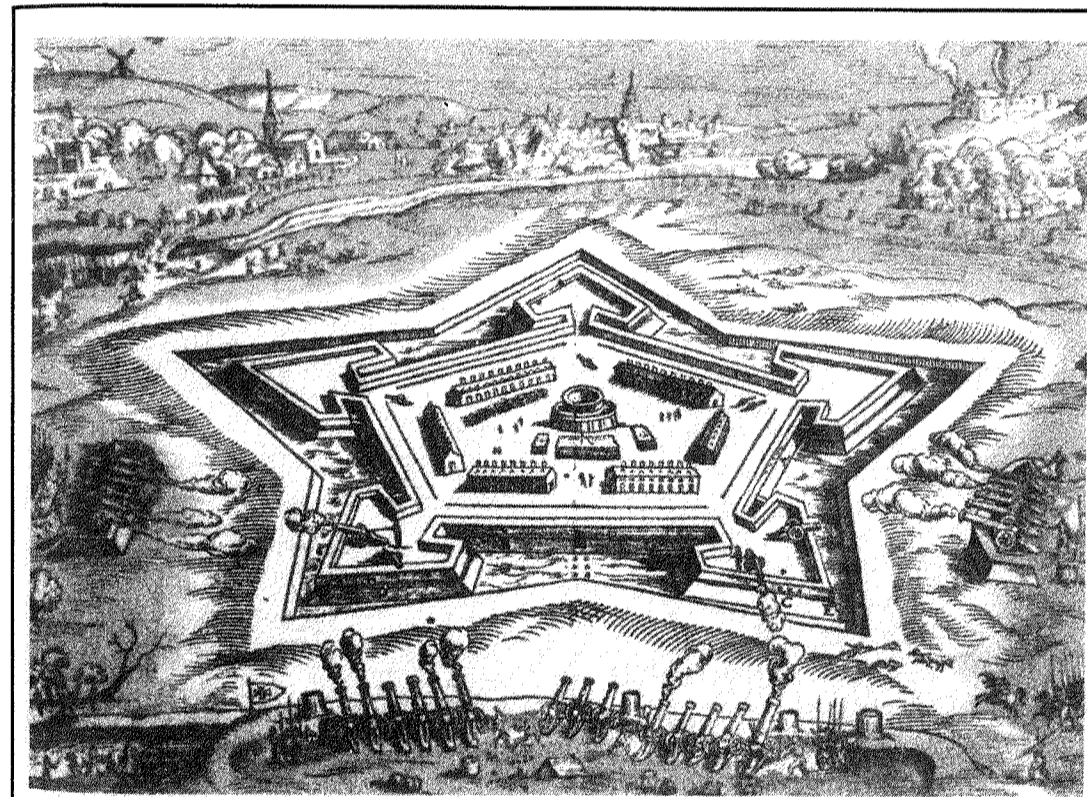
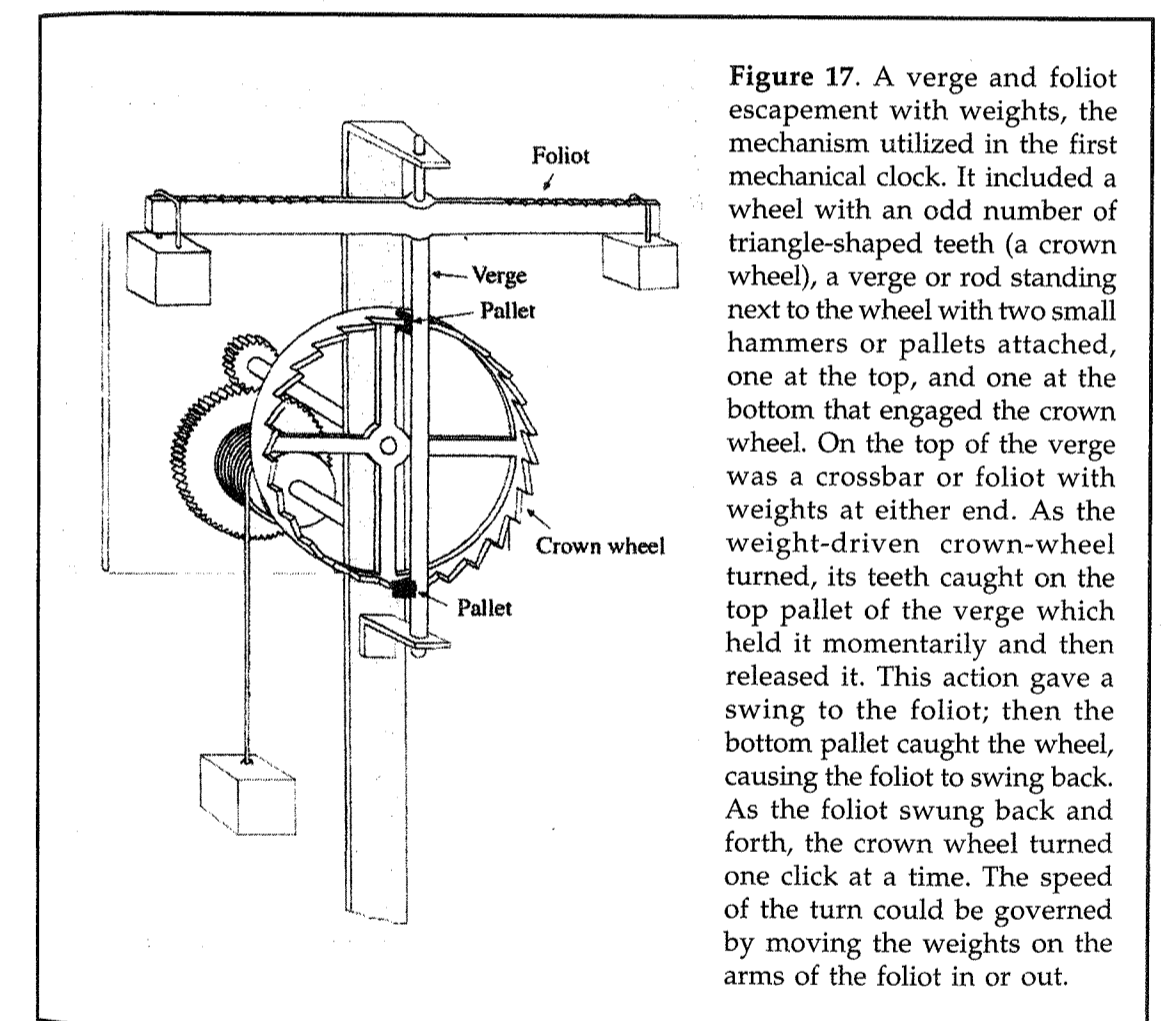


Figure 16. A fort with triangular bastions under siege (after Gabriello Busca, *Della espugnazione et difesa delle fortezze libri due* [1585], courtesy Bob Korn).

essential part of all late medieval armies. Women forged, purchased, or traded, and then prepared food. They fabricated, laundered, and repaired clothing. They cared for the sick. Women were as much a part of late medieval armies as were men. They were prostitutes or wives, bore and cared for children as they also carried out numerous tasks involving the supply and maintenance of the army.⁶

CLOCKS AND PRECISION INSTRUMENTATION

The mechanical clock is an ingenious and significant invention dating from the late thirteenth century. Undoubtedly indebted to ancient traditions of water clocks and automata, the first mechanical clock was weight driven, and worked by means of a verge-and-foliot regulating mechanism, which allowed the gradual descent of the weight and thus the slow motion of the clock (**Figure 17**). Early mechanical clocks were large iron mechanisms that were installed in towers. In the fourteenth century, a clock that struck the hours amazed the citizens of Milan. In Padua, Jacopo and Giovanni da Dondi created an astronomical clock for the palace of the ruling Carrara family. This clock showed astronomical motions, displayed a calendar showing the holy days, and told time. By the late fourteenth century, numerous cities possessed public clocks. They were a source of pride and often contained moving figures. On the famous clock in the Cathedral of Strasbourg, magi bowed at noon and a cock crowed and flapped its wings. Beyond the function of civic display, clocks symbolized orderly rule, and began to



regulate urban life. Textile workers in Flanders, for example, began to work according to the sounds of mechanical clocks.¹

Clocks had both practical and cultural uses. To give one example, in a treatise on manners extolling temperance for women, Christine de Pisan writes:

Temperance should be called a goddess likewise. And because our human body is made up of many parts and should be regulated by reason, it may be represented as a clock in which there are several wheels and measures. And just as the clock is worth nothing unless it is regulated, so our human body does not work unless Temperance orders it.²

Otto Mayr has investigated the cultural meanings of clocks in Europe from the fourteenth through the seventeenth centuries. By the seventeenth century the clock often stood for the universe itself, working in clockwork mechanical precision; it also stood for the well-regulated rule of the authoritarian state. Clocks underwent technological developments as well as symbolic ones. By the mid-fifteenth century a spring mechanism was adopted in place of weight-driven clocks. This allowed greater accuracy and permitted the development of smaller clocks, often beautifully ornate pieces that ran for weeks. In the sixteenth century further developments permitted the manufacture of watches.³

The new importance of time-measurement is indicated not only through the development of mechanical clocks, but by the fourteenth-century invention of the sandglass, or hourglass, a seemingly simple device constructed to measure specific units of time, whether a fraction of an hour, a full hour, or longer periods to more than eight hours. The sandglass was used as widely as the mechanical clock. City councils employed it to determine the start of council meetings; the amount of time that could lapse before late council members would lose their attendance fees; the time that could lapse before they were fined; and the time spent on each item of the meeting agenda. In other contexts, sandglasses regulated rounds of tournament games and the length of sermons. Scholars used them to help them work efficiently. Mine overseers used them to measure the hours that miners worked underground. Sandglasses also limited the time to which an individual could be subject to torture. In addition to its many practical uses, the sandglass became a powerful iconographic symbol for the passing of time.⁴

In addition to clocks and hourglasses, a variety of new instruments came into use, including navigational instruments developed in conjunction with oceanic voyages. Such voyages were motivated primarily by the desire for trade and riches to the east. During the early fifteenth century, the Portuguese led by Prince Henry the Navigator (1394–1460) began their efforts to circumnavigate the African continent. Early oceanic voyages were fraught with danger; as ships left familiar coastal waters for unknown seas, the traditional charts and known landmarks that guided medieval coastal

navigation could no longer be used. By the mid-fifteenth century, astronomers in Henry's court were teaching navigators position-finding by the use of celestial bodies. Astronomer's instruments were developed for navigation, including the cross staff, the mariner's astrolabe (a simplification of the older land-based astrolabe), and the mariner's quadrant. These instruments helped the sea captain find his latitude by measuring the altitude of the north star or the sun from the location of the ship. Latitude could then be determined with the aid of tables, such as one showing the sun's declination through the year.⁵

Sea captains were using the magnetic sea compass on their ships by the late thirteenth century. This device was improved in the fifteenth to become a stabilized steering compass. The discovery of magnetic variations in the mid-fifteenth century and the development of instruments and techniques to measure that variation at sea in the sixteenth, aided sea captains in locating their latitude. Yet sea charts remained inaccurate because they were made by transferring geometric projections on to a flat surface and failed to take account of the curvature of the earth. That problem was solved first by the mathematical work of Pedro Nuñez (1502–78) of Spain. Nuñez demonstrated that on a sphere a rhumb line (a line of constant compass heading) is not straight as it is on a plane, but is a spiral ending at the pole. Rhumb lines cut all meridians (imaginary north-south lines on the earth's surface that connect the geographic poles) at a constant angle. It was a Flemish cartographer, Gerhard Mercator (1512–94), who drew such lines for the first time on the gores of a terrestrial globe. In 1569, Mercator published the first sea chart in which the directions were true.⁶

Measurement in the context of navigation and cartography became an increasingly significant activity. Yet the invention and manufacture of precision instruments extended to many other realms in the second half of the sixteenth century. Around mid-century the practical mathematician Niccolò Tartaglia invented both the *squadra* or gunner's quadrant to assist in aiming cannon, and a surveying instrument to measure distance and height (of towers for example) by means of sighting and triangulation. Other inventors created a variety of new sighting instruments and surveying compasses. Near the end of the century Galileo Galilei invented a military compass known in modern terminology as a sector. The value of precision measurement was increasingly appreciated as was the artisanal skill required to create such instrumentation. Certain cities such as Nuremberg in south Germany became well known for their instrument and clock makers. Precision instruments were utilized for all kinds of tasks from navigation to timekeeping to surveying.⁷

Instruments were important to the development of the new sciences in the late sixteenth and early seventeenth centuries. For example, Galileo, after learning about a new optical instrument invented in the Netherlands, tried to obtain one but failed. He then figured out how to make one himself and

began looking through his new sighting instrument at the heavens.⁸ Galileo's "telescope" as it would later be called, was only one of many instruments that would be used to investigate the natural world in the newly developing, empirically oriented sciences that would take center stage in the seventeenth century.

BOOKS AND PRINTING

Between 1300 and 1600, thousands of books were produced, bought, sold, and read. Precisely in the middle of this period, around 1450, a new invention—the printing press—began to change the book market and its participants: authors, patrons, printers, buyers, sellers, and readers. Scholars debate the extent to which the impact of printing was revolutionary or exerted a more gradual influence. Although manuscript codices continued to be made through the sixteenth century, soon they were eclipsed by printed books.

At the beginning of the fourteenth century, manuscript books were made of vellum (cowhide) or parchment (sheepskin), or from paper, an increasingly available and cheaper product. Scribes had traditionally copied manuscript books in the *scriptoria* of monasteries. By the thirteenth century, a flourishing urban book trade had developed, especially around the universities but also supported by a growing number of readers from the urban middle classes, including humanists in the cities. Stationers who supervised the copying of books for universities conformed to the *pecia* system that involved an elaborate process of checking copies to ensure accuracy. To make a manuscript book, a leather worker purchased vellum or parchment in a crude state and then thinned, shaved, and bleached it. After the codex was created, a scribe copied the manuscript. A different artisan, the rubricator, added the large initial letters that began the chapters as well as chapter headings. Then, if the manuscript was to contain images, it went to the illuminator, a specialist in painting pictures in manuscript books who usually worked in a separate shop.¹

The technology of printing was made possible by paper, a material that arrived in Europe from China via the Arabs in the twelfth century and had become widely used by the late fourteenth. Though more fragile than parchment, paper was cheaper and easier to produce in large quantities. From the fourteenth to the eighteenth century, it was made entirely out of old linen and cotton rags, and the collection of old clothes for rags became an important business. Rag collectors worked for second-hand dealers who took the rags and sorted them before selling them to paper mills. Millers steeped the rags—that is, chopped them into small pieces and placed them in containers to ferment, forcing out fatty substances and separating the cellulose. Then they put the material into beating troughs at the mill, adding soap and water.²

This mill, usually powered by a waterwheel, contained wooden mallets connected to levers attached to the main shaft. The mallets pounded the rags, creating a thick paste or pulp that the miller then put into a vat of warm water. He inserted a wooden frame with a screen made of bronze wires. As the water drained out, a flat layer of pulp remained. The miller dried the

sheets on felt, then hung them for further drying. He coated their surfaces with a size (a kind of glue) to facilitate the proper absorption of ink. Drying the sheets again, he finished them by scraping them with flint. Gathering them into reams of 25 sheets and bundles of 20 reams, he delivered them to market. Printing presses used a huge amount of paper. Rag shortages were a continuing problem, only solved in the nineteenth century when a commercial method for making paper from wood pulp was perfected.³

A kind of printing established before the invention of the printing press was woodcut printing, or xylography. The technique of block printing on cloth, which came from the east, was well suited to paper. Block prints appeared in the late fourteenth century and proliferated rapidly. First they comprised single sheets containing only images, usually of religious subjects. Eventually blockprinters added written legends. Then small, multipage woodcut books appeared, the first books to be within the reach of the mass of people.⁴

The printing press did not develop directly from xylography. Rather, it involved a composite invention of three separate elements—moveable type cast in metal, an oil-based ink, and the press itself. For each letter, the smith made a punch from a piece of hard metal with a letter engraved on the end. The printer used the punch to strike a die in a softer metal that held the impression, or *intaglio*. He or she then used the die to make as many “sorts” or letters as desired. Smiths made the letters from metals such as tin or lead that fuse at low temperatures. Goldsmiths and minters, already familiar with using punches to make designs in coins and leather, developed the technique.⁵

Between 1430 and 1450 experiments on the invention of a viable commercial printing press using moveable type were proceeding in several locations. There is enough evidence to show that this experimental phase did occur, but not enough to know exactly who was doing what. The first successful printing business finally emerged in Mainz, Germany, and is associated with three men: Johann Fust, a rich citizen financier; Peter Schoeffer, probably a copier and calligrapher before becoming a printer; and Johann Gutenberg, who is generally accepted as the inventor of moveable lead-based type. The expenses of developing the new printing business drove Gutenberg into bankruptcy. The court cases that resulted, including Fust’s lawsuit against Gutenberg in 1455, have provided much information. Yet who did what in terms of the various inventions that led to printing is still not entirely clear. Whatever the complex processes of experiment that led to the new invention, it is plain that it involved more than one inventor. Printing soon spread all over Europe, transforming the world of books.⁶

Scholars disagree about the influence of printing on culture and society. Elizabeth Eisenstein argues that printing had epoch-making effects that permanently changed European culture. She suggests that it led to “fixity” of ideas and images, ending the errors of manuscript transmission. She contends, moreover, that it brought about the development of technical and

scientific literature; and that it allowed the reproduction of identical images through a variety of copies and editions, which led to the rise of scientific illustration. Other scholars have criticized the technological determinism inherent in this approach. Roger Chartier, for instance, has preferred to investigate the effect of printing in specific local contexts as it influenced both authorship and readership. Others have suggested that manuscript books, especially those produced by the *pecia* system, were as accurate as printed books; that “fixity” was not characteristic of early printed books; and that an expansion of books on the mechanical arts (“technical literature”) occurred before the advent of printing.⁷

LABOR, GENDER, AND THE STATUS OF CRAFTWORK

The many kinds of craft production that flourished in late medieval cities can be divided broadly into two kinds: those that were free and theoretically open to any resident, and those that were highly regulated, usually by a guild. The guilds developed in the twelfth and thirteenth centuries, first as organizations of merchants, and somewhat later as organizations of artisan producers or craft guilds. The craft guilds regulated training and apprenticeship as well as certain aspects of production. Masters who were members of the guild headed particular workshops. They supervised apprentices, who often began when they were between ten and twelve years old and who might be the children of the master. Apprenticeship lasted four to ten years. Then apprentices became journeymen or day workers who worked for wages and hoped to become masters. To become a master, a journeyman had to produce a masterpiece, and, after approval by the guild, could open his own workshop and become a guild member.¹

In addition to regulating apprenticeship and deciding who to admit as masters, guilds promulgated rules to ensure the production of high-quality goods; to protect craft secrets from wide dissemination; and to maintain monopolies on their craft in their cities, preventing nonguild members from practicing the trade. The relationship of the craft guilds to political power and authority varied from one city to another. In some cities, such as Florence, the major guilds wielded considerable power and formed part of the structure of government. In others, such as Venice, the governing body (the Venetian Senate) closely controlled the guilds.²

Whether free or regulated, craft production was tied to either long-distance international markets or to local retail markets in which buyers and sellers exchanged money and diverse goods, from ale to stockings, cloth, and pots and pans. At least in the northern cities, women largely controlled local markets, whereas men controlled international markets. The wives and daughters of masters often themselves practiced the craft, but they also kept accounts, acquired supplies, and brought products to market.³

During the thirteenth and fourteenth centuries, both men and women were extensively involved in guilds and in craft work, women often as the wives and daughters of masters, or as widows carrying on the crafts of their deceased husbands, but also on their own. A significant number of women were guild members and masters in their own right. Many crafts ceased to expand in the fifteenth and sixteenth centuries, due to long-term price inflation and other complex economic factors. Journeymen could no longer expect to become master craftsmen unless they were related to a master craftsman (as a son, for example) or married the daughter or widow of a master. Since many workers expected to remain journeymen for life, they organized

themselves into guilds. These guilds widely advocated the exclusion of women and worked to prohibit their participation in the crafts. Their views came to be generally accepted by city councils and legal bodies. Craftwomen found it increasingly difficult to practice their craft.⁴

The complex reasons for this decline in the fortunes of craftwomen is the focus of a scholarly debate. Martha C. Howell argues that high-status labor involved not just particular crafts *per se*, but labor in which individuals controlled both their own raw materials and supplies and distribution of the products of their labor. The declining ability of women to work in high-status productive labor involved complex circumstances. They include the development of market labor, the decline of family economic production units, developments in capitalism, and the solidification of patriarchal structures. Women, always banned from political power and from learned professions requiring university education, now also increasingly experienced economic strictures in the practice of the crafts, even as widows and as heads of households.⁵

In a very different development, certain kinds of skilled craftsmen were able to remove themselves from the purview of the guilds and work as clients of elite patrons. These include artist/engineers such as Francesco di Giorgio and Leonardo da Vinci. The elevation of certain mechanical arts, including painting and architecture, to higher-status liberal arts aided the rise of the artist/engineer. In the sixteenth century in some areas such as Florence, painting came to be taught and developed in academies patronized by noble rulers, rather than in workshops controlled by master craftsmen and guilds. Practitioners not only painted, sculpted, and designed and built buildings, they also wrote treatises about these practices. In the fifteenth century, they dedicated manuscript books to patrons; in the sixteenth, they dedicated printed books to patrons as they also participated in the book market.⁶

Such practitioners exerted significant cultural influence. In modern times individuals such as the artist/engineer Leonardo da Vinci, the sculptor and painter Michelangelo, the painter and printmaker Albrecht Dürer, the goldsmith Benvenuto Cellini, and the painter Vasari, who wrote the famous *Lives of the Painters*, have all come to represent the creativity and individuality of Renaissance art production. In their own times, such men helped to create a culture in which making things and visual representation began to enjoy higher status and to be connected to the investigation of the natural world. They did this through their communication with elites interested in the constructive arts; through writing treatises about their disciplines; and through their positive valuation of handwork. New modes of investigation were based on experimentation (involving the manipulation of instruments and machines) and on observation. Other artisans constructed precision instruments and discussed them with learned individuals interested in using them for navigation and surveying. The two separate worlds of the mechanical arts and university learning that prevailed in the fourteenth century had come to be far closer in the late sixteenth, creating the necessary conditions

for the development of the new experimental sciences of the late sixteenth and seventeenth centuries.⁷

CONCLUSION

Far from being a mere chronicle of inventions, the history of technology is integral to almost every aspect of human history. It includes a concern for traditional techniques and complex new technological systems. The history of technology concerns large-scale construction, hydraulic projects, mills, cathedrals, and bridges—that is, a history of engineering—but it is far broader than such a history. It is about making and using objects, about craft processes and construction. Yet objects are not only material but also social and cultural entities. They are constructed and used by individuals and groups of people who assign meaning and value to them. As people in all human history live within an intricate web of materiality, they also assign meaning and values to all aspects of that materiality. The material matrix of history is also a cultural matrix; historians of technology insist that the cultural matrix must also be understood within the framework of its material manifestations. Adhering to the multiplicity of objects and their production are issues of status and value, of power and knowledge. Consideration of the production of things and all the myriad processes, organizations, and social and material considerations that go into that production, are crucial elements for the construction of a history that reflects the lives of the peoples of the past. The transitional period between 1300 and 1600 produced an amalgam of old and new crafts, craft processes, inventions, and technologies.

The history of technology for these centuries can be written from many points of view. One involves the individual producer, whether it be a spinner making wool yarn, a smith hammering a wrought-iron pot, mineworkers excavating silver ore, a peasant family producing grain crops, or a family cook, collecting ingredients for and preparing a meal. Such individual producers are invariably influenced by a combination of material constraints and cultural influences, including the nature of their own training and skill.

Another point of view involves the users or consumers of technology and its products. Consumers of technology include virtually every member of society. Such consumers are profoundly influenced by issues of gender, age, class, and regional culture. Some consumers of clothing in late medieval Europe, for instance, increasingly engaged in conspicuous consumption, as they were also sometimes affected by sumptuary laws that attempted to regulate the apparel of certain groups (Jews and women, for example) and classes. Consumers included everyone. While princes might wear silks, furs, and jewelry made of precious metals and stones, peasants wore cheap woolens. The habits of consumption of peasants, I would argue, were every bit as significant as those of princes. The purchasing power and cultural influence of the wealthy and powerful were balanced by the far greater numbers of middle-level and economically impoverished groups.

Historians of technology in this period have often focused on invention, whether it be the invention of the spinning wheel or improvements in the windmill, developments involving silver ore processing or new agricultural techniques, the printing press, or any of the other numerous technical innovations that appeared between 1300 and 1600. Traditionally, they have studied such inventions in relative isolation from the wider historical context, and have tended to view them solely as positive developments. Now, historians increasingly appreciated that inventions and their wider adoption always occur within a context that includes interaction with many other facets of culture, including traditional technologies and techniques.

Part of the context of invention involves any particular culture's valuation of novelty and inventiveness itself. There is evidence that between 1300 and 1600 inventiveness was valued, as Bacon's statement at the start of this booklet attests. Yet no claim can be made that inventiveness was universally prized. A much less well-studied subject is the positive valuation of traditional technologies, something that was also widely present during these centuries. Rather than tying inventiveness to an uncritical assumption of progress, we might ask the following questions. "Progress for whom?" "Progress in terms of which particular factors?" "What were both the positive and negative implications of technological change for the peoples who were affected by them?" "Why were certain innovations adopted and others not?"

The history of technology for the transitional centuries between 1300 and 1600 is complex and multifaceted. Diverse technologies influenced individuals and groups in a variety of ways. This booklet has tried to point to some of the complexity of the subject and to urge recognition of that complexity as an interpretive stance. More prevalent than oversimplification, however, is the invisibility of technology in the great majority of histories of the period. Material culture, including the production and use of goods and products, affected everyone and virtually every aspect of society and culture. Technologies were never inert or unchanging, nor were they ever exempt from either material or cultural considerations. Because technology in the broadest sense was intrinsic to late medieval and Renaissance society and culture, greater attention to technological history promises to enrich the history of the period as a whole.

NOTES

INTRODUCTION

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CHAPTER 1

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CHAPTER 2

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