An artisan 'revolution' in late medieval and early modern Europe?

Maarten Prak

Utrecht University

m.prak@uu.nl

Summary

In the Late Medieval and Early Modern periods, European crafts profited from a series of changes in the quality of productive knowledge and its transmission. These changes affected the formalization of craft education through apprenticeships regulated and registered by guilds, the certification of skills qualifications, novel ways of visualizing craft knowledge in print and painting, the publication of craft manuals, and finally the reproduction of such visual and textual materials in cheap printed works. Many of these changes took place during the fifteenth century, the acceleration phase of the artisan 'revolution'. In almost all of these changes European crafts were distinct from their counterparts in Asia and the Near East. In themselves, none of these changes was revolutionary, but taken together they put European crafts on a trajectory of quality improvement and innovation that would in the long run create the launch-pad for the Industrial Revolution.[1]

Introduction

Questions about the technological origins of the Great Divergence, or the Industrial Revolution, have mostly focussed on a specific type of 'knowledge'. It seems reasonable to assume that, somehow, 'knowledge' played an important role in both the development of the steam engine and the other 'gadgets' that helped launch the Industrial Revolution, as well as cause Europe's and Asia's industries to drift apart. It is less self-evident that theoretical knowledge was the key component. In his history of the knowledge economy, Joel Mokyr has made a useful distinction between theoretical and practical knowledge. The first type answers 'why' questions, the second type addresses issues of the 'how'

[1] This paper was written for a conference in February 2013 organised by Ting Xu (Belfast) for the URKEW-project led by Patrick O'Brien at the London School of Economics, and sponsored by the British Academy. Karel Davids (Vrije Universiteit Amsterdam), Huigen Leeflang (Rijksmuseum, Amsterdam), and Pamela Smith (Columbia University, New York) helped me with vital references.

category.[2] To put it another way: the first type is the realm of the natural sciences, for the second type we want to consult the engineers. Craftsmen were the engineers of the past. It is the claim of this paper that European artisans-engineers changed their practices to such an extent in the centuries preceding the Industrial Revolution and the Great Divergence that their contribution to these momentous processes needs to be re-evaluated.

Although Mokyr seems to assume that to execute designs one has to know and understand the underlying principles,[3] there is actually quite some evidence that this is not necessarily the case. As I have argued elsewhere, Gothic cathedrals and similar mega-structures were built all over premodern Eurasia by builders who had only an intuitive sense of the mechanical principles at work in their products. Nonetheless, the survival of such products across the centuries is testimony of the quality of their work. In that earlier paper I argued that medieval builders arrived at their solutions by combining the application of some very simple basic rules with experimentation.[4] During the Renaissance, however, some artisans started to look more systematically for underlying regularities, and share their insights with fellow practitioners. Others were less interested in principles, but nonetheless started to articulate at least some of the practices of their craft.

This was in itself no mean feat, because a lot of craft knowledge was (and still is) really impossible to capture in words. Having been explained how to make something properly is not exactly the same thing as being able to perform the task correctly, as everybody with training undergraduate students will have frustratingly experienced. The reason for this is actually quite simple: 'how' knowledge is fundamentally different from 'why' knowledge in that often it cannot be put in words. Whereas theoretical knowledge may look obscure to the non-initiated, it should ultimately be accessible through written or printed text. Practical knowledge, on the other hand, needs to be experienced and to become 'embodied'. Driving a car is perhaps a familiar example; it cannot be learned from a manual, but only behind the wheel. This is true for a lot of craft work as well. How to properly build a brick wall, assemble a watch, or indeed write a PhD-thesis is

[2] Mokyr 2002: 4-5.
[3] Mokyr 2002: 13.
[4] Prak 2011; also Smith 2004; Harkness 2007.

always the result of lots of practicing, because elements of that skill are by definition impossible to articulate. These tacit, or implicit elements of craft knowledge were much more important in the era before the emergence of modern science and engineering, when the discovery and analysis of natural processes themselves was depending to an important extent on the skill of craftsmen.[5] By implication, the transmission of these skills was likewise fundamentally important for the premodern economy to improve its standards of industrial production. To put it in a different way: the social organisation of skills training and transfer could make a huge difference between one system of production and another. The European artisan 'revolution' was first and foremost a series of innovations in this area.

Historical research of the past 25 years or so has made it increasingly plausible that we should consider the contribution of the crafts in four distinct and relevant areas.[6] In the first place, social and economic historians have observed that craft guilds established a regulated system of apprenticeships, as well as certification of the results of training for independent producers. Even though guilds as such were not unique to Europe in the premodern world, the formalised examination of apprentices probably was. Secondly, historians of science discovered that from the fourteenth century some European craftsmen were writing down their craft practices and distributing them to colleagues as well as a lay public, first in manuscript, but from the late fifteenth century also in print. The increasingly easy access to craft knowledge again seems to have been a uniquely European phenomenon. Thirdly, craftsmen of the Renaissance were interacting more often than their predecessors with scientists and scholars. There is evidence to suggest that the same also happened in China. However, in Europe this interaction led to a development of theoretical statements that has no equivalent in other parts of the world at the time. Finally, as art historians have known for much longer, European artists developed new methods for a realistic, two-dimensional representation of the natural world, on paper and in print. The increasingly sophisticated skills of European artists and artisans to represent not just the Holy Family or saints, but also buildings and machines,

[5] Epstein and Prak 2008: 5-7; Mokyr 2009: 46-47 subtly restates the author's position.
[6] The literature about all of these topics is vast and I have tried to focus on the more recent publications. Even then I am aware that at this point I have merely scratched the surface.

also contributed significantly, this paper claims, to the acceleration of industrial innovation in late medieval and early modern Europe.

What, when, where, and why?

The artisan 'revolution' consisted of a series of improvements in the transmission of craft – i.e. practical – knowledge that created a dynamic which helped to improve both the quality of that knowledge and its dissemination to an expanding number of practitioners. This was a slow process, which is the reason why the word 'revolution' has been consistently placed between inverted commas in this paper.

The artisan 'revolution' covered at least half a millennium, and it is difficult to identify a point-of-no-return. The establishment of craft guilds in the thirteenth and fourteenth centuries was the foundational stage. However, it was followed by certification of skill through the production of a masterpiece, and the emergence of craft manuals from the later fourteenth century, the increasing collaboration between craft practitioners and humanist scholars during the Renaissance, and the further distribution of the fruits of such collaborations in print from the late fifteenth century onwards. The fifteenth century therefore was the acceleration phase. This was followed by a stage of consolidation, in the sixteenth, seventeenth and eighteenth centuries, when techniques were further improved and written and graphic knowledge reached ever larger numbers of craftsmen. In the consolidation stage significant steps forward were made that can be seen as part of the same process, for example with the establishment of drawing schools from the late sixteenth century onwards.[7]

The artisan 'revolution' was an urban phenomenon. There was industry in the countryside, but high-quality industries tended to be concentrated in medium-sized and larger towns. Unsurprisingly, therefore, the component parts of the artisan 'revolution' also had strong urban elements: the guilds, the printing press, humanist scholarship. Northern and Central Italy were in many respects the cradle of the innovations of European crafts, as will be demonstrated in subsequent sections of this paper. From Italy these innovations rapidly spread to other regions of strong urbanisation, most notably

[7] De Munck and Soly 2007: 7.

southern Germany and the Low Countries. These regions not only shared high percentages of urban populations, but were also characterised by a multitude of towns.

This combination of high rates of urbanisation and dispersal of the urban population across a large number of spatial clusters also helps to explain the dynamic of the artisan 'revolution'. Its geography at one and the same time encouraged mobility from one centre of production to another, as well as competition between those centres.[8] The involvement and preoccupation of urban governments with local industries testifies to the significance that contemporaries ascribed to such local industries, and their willingness to promote them.[9]

Case study: Albrecht Dürer

The artisan 'revolution' was embodied, as it were, in one single individual: Albrecht Dürer from Nuremberg, Germany. Clearly, Dürer was an exceptionally gifted individual. His work has given rise to a whole body of scholarship, because of his versatility and the quality of his work.[10] But it is also precisely for this reason, and because Dürer has left us a substantial number of diaries, letters and publications, reflecting on his own work, that he is singularly suited to illustrate the various dimensions of the artisan 'revolution'.

Dürer, who was born in 1471, came from an artisan family; his father was a goldsmith in the town of Nuremberg, one of the most important centres of cultural industries in early modern Germany.[11] Dürer himself was initially apprenticed as a goldsmith, but received permission to switch to the visual arts, not a radical step when we realise that goldsmiths were supposed to draw as well. Young Albrecht proved very gifted, to judge from early works. A self-portrait at sixteen suggests a maturity of skill unusual at such a young age. As was customary, Dürer travelled for several years after his apprenticeship, and one of the places he visited was Colmar, home of the most accomplished engraver of his day, Martin Schongauer. Unfortunately, Schongauer had died just weeks before Dürer's arrival. He must have been able to see his work, however,

[8] De Vries 1984: 158-72; De Vries 2001; Mokyr 2002: 275-82; Gelderblom and Grafe 2010: 509-10; Smith 2010: 29; Davids 2013a: 203-04, 221.
[9] Cipolla 1980: 189-90; Davids 2008: 413-16.
[10] Hutchison 2000; for recent works, see bibliography in Hess and Eser 2012.
[11] For Dürer's biography, see Hutchison 1990, and Wolf 2010. Nuremberg's cultural industries are highlighted in *Gothic and Renaissance art* 1986.

and communicate with, perhaps even work in, Schongauer's workshop. He also visited Italy before he reached the age of 25. In the meantime, Dürer had married and settled down in Nuremberg. He was to travel to Italy again in 1505-7, and to the Low Countries in 1520, and thus managed to visit the most important artistic regions of his times.

During his lifetime Dürer already became a celebrity. His travel notes from his trip to the Low Countries read like the tour of a pop star. Wherever he went, he was invited to meet famous people and wined and dined by fellow artists. In Italy he had to pursue imitators through the courts. He introduced a special trade-mark, consisting of his initials, to protect the revenues from his prints. He was engaged as court painter by the Holy Roman Emperor, while his engravings sold well. He was a very productive artist; almost 100 paintings, over 100 engravings and 157 woodcuts and over 1,000 drawings have survived (Schmid 2003: 544). His art made Dürer a wealthy man. His self-confidence is perhaps nowhere more in evidence than in the self-portrait from 1500, where he is dressed like Jesus and locks eyes with the spectator (Eichler 2007).

A very important influence on Dürer's work was his friendship with local humanist luminary Willibald Pirckheimer. Pirckheimer was possibly the most celebrated scholar of his days in Germany and it was Dürer's good fortune that he happened to live in Nuremberg. Dürer was also close to another Nuremberg humanist, Konrad Celtis. Pirckheimer had studied in Padua and Pavia and spent a total of seven years in Italy. He translated from the Greek into Latin at a time when no German universities taught Greek. He also owned a large book collection and regularly hosted meetings for humanists scholars and artists, where Dürer had a standing invitation. Pirckheimer subsidised some of Dürer's foreign travels and introduced him to various contacts, in Germany and Italy, but also to Erasmus in Antwerp. Equally important was his suggestion of various classical themes for Dürer to work on, as well as his encouragement to master the Italian theories of perspective, which Dürer would subsequently publish in his handbook on the topic.[12]

Because, remarkably perhaps, Dürer was not satisfied to be one of the most successful and celebrated artists of his day, he also took it upon himself to share his insights with other practitioners. He wrote several treatises, two of which were published

[12] Hutchison 1990: ch. 5.

during his lifetime, a third posthumously. For reasons of coherence we will disregard the treatise on fortifications and architecture, although it has to be said that this added another string to his bow. In 1525, just before he was to die in the next year, and in 1528, works by Dürer were published on geometry and on human proportions. Both were dedicated to Pirckheimer. In both he claimed that earlier authors from Antiquity would have done a far better job than he could, but that unfortunately their works were lost so that their knowledge had to be rediscovered and re-articulated. The work on geometry had been written with those in mind 'who are eager to become artists', and provide them with 'a starting point and a source for learning about measurement with ruler and compass'. Specifically, he reminded his readers that skills were easily lost but difficult to recover; that is why he decided to record those skills and practices. He also stated that goldsmiths, sculptors, stonemasons and carpenters might find the contents equally useful.[13]

His Four Books of Human Proportion were similarly concerned with practical skills. Like the geometry volume the whole approach was very hands-on. The text was set in first-person singular, as if Dürer was in the room, demonstrating the various procedures. This effect would have been even stronger when the text was read out, as was still customary in the early sixteenth century. The lay-out added to the practicality: not only was the text supported by numerous illustrations, but these were printed on the opposite page, so that one could see and read simultaneously. Especially the book on human proportions contained very little theory, and instead concentrated on the job at hand. The human form was subdivided into men and women, young and old, providing quite a rich range of types. Moreover, Dürer warned his readers against slavishly following his recommendations. On the contrary, he insisted that the reader should not follow the rules as if they were set in stone, but to rather use them 'as long as he pleases, or finds a better way'.[14] In his geometry book, he likewise suggested that 'those who do make use of them not only as a beginning but daily, will reach greater understanding and will seek and then find much more than I have said here'.[15] In other words: for Dürer craft knowledge was serious – and never finished. Dürer's work on human proportion

[13] Dürer 1977: 37.
[14] Dürer 2011: 21.
[15] Dürer 1977: 37.

was published in German and in Latin in 1528, in French in 1557, in Italian in 1591, in Portugal in 1599, and in the Netherlands in 1622.[16]

Dürer is a singular case, precisely because he combined all the various aspects of the artisan 'revolution'. However, the fact that he managed to do so, demonstrates how far the artisan 'revolution' had progressed by the early sixteenth century. From this point on, the macro inventions and innovations of the fifteenth century had to be consolidated and disseminated.

Skills, training, and guilds

One of the implications of the tacit character of craft skills is that they can only be acquired through inter-human, person-to-person interactions. Aspiring craftsmen have to learn their trade from experienced practitioners. The traditional – and perhaps also original – setting for such transmission is the household. European guilds, however, from very early on, took responsibility for apprenticeship and helped create a system in which a much wider circle of people supplied access to craft knowledge.

Much ink has been spilt on whether or not medieval craft guilds were some sort of a continuation of Roman confraternities, but the *communis opinio* now is that they were basically a fresh start.[17] Their emergence broadly coincided with the revival of urban life in the High Middle Ages. The earliest reliable evidence for the existence of a craft guild comes from the middle of the twelfth century and relates to the weavers of Cologne. Evidence for early guilds has also been discovered in Southern France and Northern Italy. In the course of the thirteenth century, craft guilds increased in numbers in the original regions, but also spread to other parts of Europe. The London cappers, for example, were granted a set of 'articles' in 1270.[18] By the early fourteenth century the craft guilds of the industrial centres in the County of Flanders were powerful enough to destroy an army of French knights at the Battle of the Spurs and install guild regimes in the county's towns and cities. By the end of the fourteenth century over four hundred craft guilds had been

[16] Dürer 2011: 1-3; slightly different dates for the translations in Golahny 2003: 88.
[17] S.A. Epstein 1991: ch. 1; Kluge 2007: ch. 2.1.
[18] S.A. Epstein 1991: ch. 2.

established in the territories that nowadays make up Belgium; 150 of those existed in Flanders alone.[19]

Craft guilds were combining a variety of roles.[20] They worshipped a patron saint together. They lobbied local governments for legislation favourable to the trade. They sometimes accepted responsibility for public services like fire fighting or militia duties. To improve their bargaining position, and perhaps to also make life easier for their members, they attempted to restrict access to the craft to their members only. And they regulated apprenticeship, i.e. the training of the next generation of practitioners. Gradually, European guilds started to include two important conditions for membership: 1. new members had to provide proof of their expertise by performing a test, and 2. only those who had served an apprenticeship, preferably with one of the members of the guild, were allowed to sit the exam. Almost inevitably, such exams were also socially selective.[21] Chinese guilds did have regulated forms of apprenticeship, but no testing of acquired skills.[22] In the Near East apprenticeship was less formalized than it was in Europe, and certification of acquired skill seems to have been introduced only in the nineteenth century.[23]

Early craft regulations from the Dutch towns of Utrecht and ’s-Hertogenbosch (Bois-le-Duc) demonstrate little concern for apprentices. The assumption is that apprenticeship was arranged according to custom. In ’s-Hertogenbosch the first regulations that discuss apprenticeship in detail, date from 1377 when the local fullers received a set of rules. In the fifteenth century, regulations concerning apprentices were quickly becoming standard elements of new craft rules. Moreover, terms of apprenticeship tended to become longer during the fifteenth century. At the same time, concerns with other elements of quality control were also increasingly articulated in rules and regulations. The first regulations to mention a masterpiece were issued in ’s-Hertogenbosch in 1422 and they became a standard feature in the sixteenth century.[24] In

[19] De Munck, Lourens and Lucassen 2006: 37.
[20] For recent work on craft guilds, see Prak, Lis, Lucassen and Soly 2006; Kluge 2007; Epstein and Prak 2008.
[21] De Munck 2007: 68-84; also De Munck 2008.
[22] Moll-Murata 2008: 223.
[23] Baer 1982: 156, 176; Ghazaleh 1999: 56; Yi 2004: 52-53.
[24] Overvoorde and Joosting 1896-97, vol 2; Van den Heuvel 1946a: 43; Van den Heuvel 1946b: 60-74, 89.

the towns of Flanders and Brabant master pieces were likewise introduced during the fifteenth century and became customary during the sixteenth.[25]

We know that the master piece was not required by all craft guilds at all times, but so far the indications are that passing the exam became the normal route to membership. It has been established for seventeenth-century England that more than half of all apprentices failed to take the exam. However, those who aspired to open a workshop and thus had to acquire membership of a guild, almost invariably completed the seven-year apprenticeship that allowed them to take the test. As a result, those in charge of industrial workshops in seventeenth-century English towns had demonstrated their skill by producing a sample product to the satisfaction of the examiners.[26]

Guilds did not regulate the contents of the training as such. In some places, as for instance medieval Genoa or early modern Paris, this was left to separate notarial contracts, which would still be phrased in quite general terms, requiring the master to share 'the secrets of the trade', or 'mystery of the craft', with his apprentice.[27] Contracts also spelled out details like the amount of money the apprentice's parents or guardians were paying for the boy's education, as well as his room and board. These contracts, however, presupposed the existence of a regulatory framework as supplied by the guild.[28] S.R. Epstein has suggested that guild regulation was needed to overcome the imbalance between the interests of the apprentice who was learning the craft during the early stages, and the master who stood to profit from the apprentice's labour during the later stages of the contract. Given the number of drop-outs observed in early modern London, this cannot have been more than one part of the explanation.[29] The fact that both the regulations and the meticulous registration of apprentices seem to prioritise the administrative side of the education suggests that contemporaries may have found it difficult to articulate tacit knowledge which was also subject to changes as industries innovated. However, it is more likely that the guild's primary responsibility was to make sure that apprentices' education as such was properly recorded. The outcome would have been covered by the final exam constituted by the requirement to produce a master piece.

[25] Munck 2007: 68.
[26] Wallis 2008: 839.
[27] S.A. Epstein 1991: 63-76; Kaplan 1993: 437-41.
[28] S.A. Epstein 1991: 68.
[29] Wallis 2008: 853-54.

It has been estimated that in 1700 a quarter of British males aged 21 had completed an apprenticeship. An alternative estimate sets the figure as high as two-thirds, but given the drop-out rates that percentage can only refer to males who had some apprenticeship experience.[30] The British workforce had a reputation for being exceptionally well-trained.[31] The legal statute of apprenticeship, moreover, covered an unusually wide range of professions, not all of them incorporated. All of this nonetheless suggests that perhaps in Europe's urban populations as much as 25 per cent on average of all boys, and quite a few girls as well, would have passed through the corporate apprenticeship system.[32]

Through their regulation and administration of apprenticeships, European craft guilds thus started to make crafts training into a formalised type of education in industrial skills. This education became separated from the family and was, in the majority of guilds, concluded by a formal exam, at least for those apprentices who aspired to set up shop as an independent craftsman.

Craft manuals

In the fourteenth century a new type of texts suddenly started to appear.[33] Instruction books potentially shared the so-called craft 'secrets' with a wider audience than oral transmission might. Initially, the access to such texts was limited by the sheer problem of hand copying, which made the written word very expensive, probably too expensive for the large majority of craftsmen. The invention of movable type in the mid-fifteenth century would help to overcome that problem, but we will discuss this separately below.

These early instruction books, which we will call manuals, dealt with a quite specific range of topics: the preparation of food, the working of metals, the building of military defence works, and medical issues all tempted authors to share their knowledge in written form. However, increasingly other industries were drafted into the movement: the visual arts, and civic building, including maritime projects, but also machine making, to name only some of the best-known. Such works combined very precise observations

[30] Mitch 2004: 340; Humphries 2009: ch. 9.
[31] Mokyr 2009: 107-109.
[32] For female apprentices, see e.g. Crowston 2005: ch. 7.
[33] Medieval 'recipe' books were overwhelmingly limited to medical issues: Crossgrove 1994.

about the preparation of certain products with general comments on how things were done properly, or what the underlying principles were.[34]

Most – but not all – such manuals were written by people who were experienced in the craft, by practitioners in other words. Few of them were, however, also experienced authors, and one problem many of them faced was the absence of an established vocabulary with which to express the complex procedures required by many craft techniques. A vocabulary, moreover, that they had to share with their readers to allow for useful and reliable communication. Characteristically, many manuals invented that vocabulary as they went along.[35] New systems for information management were developed in these centuries to deal with the flow of new knowledge that came on stream. These included dictionaries and alphabetical indexes.[36]

One of the big issues of the literature on these manuals is who exactly the intended readers were. It is quite clear that this can never have been only artisans. The manuscript manuals produced during most of the fifteenth century were financially out of reach for all but the very wealthiest artisans, who also may have found it difficult to get access to such manuscripts. On the other hand, Lorenz Lechler's 'Instructions' for his son about how to build a church, must have been at least accessible to one fellow practitioner.[37] Some manuals were designed and published as coffee-table books, and seem to have targeted an audience of interested lay people, who might (or might not) act as patrons for the craft portrayed in the text.[38] In those cases, the purpose of the text was to woe investors, by giving them some sense, and therefore confidence, in the procedures practiced by craftsmen. Girolamo Ruscelli's *Secreti nuovi*, first published in Venice 1555 under his pen name of Alessio Piemontese, reached an even wider audience as; it turned out 'one of the most extraordinary popular success of sixteenth-century literature'. Within fifteen years of its appearance it had gone through fifty editions, including translations into Latin, French, German and Dutch.[39]

[34] Smith 2011: 56, 59.
[35] Smith 2004: 80-82.
[36] Blair 2010.
[37] Shelby and Mark 1979.
[38] Edgerton 1991: 148-49, 187; Wheeler 2009: 11; Popplow 2004: 20-28.
[39] Eamon and Paheau 1984: 330 (quote); Eamon 2011: 25; Smith 2011: 52.

However, some of the detail, as well as the hands-on style of many of these manuals, suggests that practitioners themselves were also seen as intended audience. Listen to this section from Cennini's *Libro dell'Arte*:[40]

> To begin with, get some lapis lazuli. And if you want to recognize the good stone, choose that which you see is richest in blue color, because it is all mixed like ashes. That which contains least of this ash color is the best. … Pound it in a bronze mortar, covered up, so that it may not go off in dust … When you have this powder all ready, get six ounces of pine rosin from the druggists, three ounces of gum mastic, and three ounces of new wax for each pound of lapis lazuli; put all these things into a new pipkin, and melt them up together. Then take a white linen cloth, and strain these things into a glazed washbasin.

It is difficult to imagine how this might be of interest to a non-practitioner, and this was equally true for the section on 'what kind of bone is good for treating the panels':

> Take bone from the second joints and wings of fowls, or of a capon; and the older they are the better. Just as you find them under the dining-table, put them into the fire.

And so on. Note the direct way in which the reader is addressed as a colleague.

Questions have been raised about the practicality of many of these manuals. This, however, seems to miss two important points about them. The first is that manuals were written for people who had some previous experience of the craft and were able to combine the written instructions with what they already knew and were able to produce. The second is that, as Smith has argued, manuals can be read as attempts to systematise and consolidate bodies of knowledge that had so far resisted, or escaped articulation. In explaining how to make things, manuals also attempted to explain the underlying mechanisms, for example of chemical processes. This was, moreover, knowledge that had been produced collectively, by the community of practitioners.[41] Even though manuals often advertised themselves as 'books of secrets', there was in fact very little that was secretive about them. Obviously, the very act of publishing secrets undermines the whole purpose of secretiveness. The reasons why these were 'secrets' was that this

[40] This and the following quote from Cennini 1954: 5, 37; cf. Smith 2004: 96.
[41] Smith 2010.

was not common knowledge, and could not be easily accessed by those who were not practitioners of the craft, or in other words: who were not part of the 'mystery' of the craft. Sharing this 'mystery' with a larger audience, consisting of both practitioners and interested laymen through the written word, was the main purpose of the manuals. Their novelty was not in the attitude of openness, but in the means of communication, shifting from the individual to the general.[42]

It has also been observed that it would be difficult to produce satisfactory results by strictly following the recipes of these manuals, but perhaps that was not the point. Practitioners had picked up the basic skills from an apprenticeship, from colleagues, or through their own experience. They would combine that knowledge with written information, rather than simply following the instructions from paper. As Lechler recommended to his son:[43]

> Give to this writing careful attention, just as I have written it for you. However, it is not written in such a way that you should follow it in all things. For [in] whatever seems to you that it can be better, then it is better, according to your own good thinking.

We have seen how Albrecht Dürer made similar recommendations in his manuals. This suggests that these manuals, insofar as they targeted an audience of craft practitioners, provided supplementary information, rather than basic skills.[44] It is against this background that we must understand the presence of Dürer's book on human proportions in Rembrandt's workshop, more than a century after the original was first published. Rembrandt, who was himself a prolific etcher, also owned numerous prints designed by Dürer.[45] Likewise, Pieter Saenredam, a contemporary of Rembrandt who specialised in the depiction of church interiors, owned copies of Dürer's books on human proportion and geometry, as well as works by Serlio, Scamozzi and Vitruvius about architecture. Saenredam had collaborated with several architects, as well as with the surveyor, mathematician, astronomer and military architect Pieter Wils, who may have taught him a

[42] Long 2001: 245; Davids 2005; Wheeler 2009: 7-9; Smith 2011: 51.
[43] Shelby and Mark 1979: 115.
[44] Kaufmann 1975: 276-79.
[45] Golahny 2003: 88-95.

lot about geometry.[46] The manuals were one among many sources of knowledge available to Dutch painters.

Crafts and sciences

Traditionally, the worlds of science and of the crafts had been completely separate. Medieval science was theoretical, or rather philosophical, and had little use for empirical data. Craft knowledge, on the other hand, was not consolidated in writing.[47] There was not much opportunity for communication between those two. From the fifteenth century this started to change with the emergence of the craft manuals discussed in the previous section.[48]

The emergence of a craft literature had at least three consequences for the interactions between crafts and science. First of all, craft knowledge became accessible to an audience of non-practitioners. It seems that beyond their colleagues, craft authors of such manuals attempted to reach precisely such readers.[49] Secondly, craft authors were forced, perhaps for the first time, to organise their knowledge in more systematic ways, which made it easier to connect to scholarly knowledge.[50] Thirdly, craft authors increasingly checked out works by scholarly authors for help and inspiration.[51]

In the process, craft practices helped to shift science from philosophical to more empirical attitudes. Craft practitioners and scientists worked closely together. In Amsterdam, Willem Jansz. Blaeu, who founded what was arguably the most important map-making firm of the seventeenth century, had worked as an apprentice for Danish astronomer Tycho Brahe.[52] In London, they lived in the same neighbourhoods and streets, which became informal 'laboratories' where artisans and scientists together tried to unravel the mysteries of nature and developed the sort of 'hands-on, experimental practices' that were to be the hallmark of the Scientific Revolution.[53] Through their descriptions of the characteristics of natural materials and the close observation of nature,

[46] Ruurs 1987: ch. 4.
[47] Smith 2004: 7; Long 2001: 72-73.
[48] Eamon 1994: 87-89; Long 1997; Long 2001: 127.
[49] Smith 2010: 34-35.
[50] Cormack and Mazzio 2005; Smith 2011: 56, 59, 65-66.
[51] Eamon 1994: 84-85
[52] Van Netten 2013.
[53] Harkness 2007: 8 (quote), 13 (quote), 30, 258.

artisans and artists helped to bring about a 'reorientation of western European attitudes toward the material world'. The observation and analysis of nature and natural processes opened the way to their systematic manipulation for the profit of mankind.[54]

In China, scientists likewise took an interest in craft techniques and knowledge, especially in the seventeenth century. This interaction was framed, and encouraged, by the institutions of the state. The main difference with Europe, however, was that the written results of such interactions were only available in manuscript form or woodblock print and therefore accessible to a mere handful of practitioners. Song Yingxing's 'Works of Heaven', a major work of craft know-how from the mid-seventeenth century was published in two editions, in 1637 and the 1650s respectively. It seems that on both occasions no more than fifty copies were produced of the work.[55]

Prints and the emergence of a visual culture

Until around 1400, all visual materials in Europe were hand copied. This, in itself, already seriously limited the use of visual material in books. The scriptoria where manuscripts were copied employed people who were skilled in writing, but not necessarily in drawing pictures. Although it would be feasible to have pictures copied by specialists, this happened only on a very limited scale. Pictorial elements that were included, usually had the purpose of making the text look more attractive, rather than elaborating on it. The invention of woodblock pictures shortly after 1400 changed that.

The technique had been known in China already since the eighth century, so Europe had a lot of catching up to do, but in the following century or so it managed to do that. The first prints to have survived the ages date from the 1420s. These were single-sheet productions with religious images. Their purpose was almost certainly devotional: they supported the faithful in their prayers and contemplations. The reasons why prints first emerged at the time remain obscure. Neither radical changes in religious practices, or newly emerging markets can be readily identified.[56] This may, therefore, have been a supply-driven innovation. From the 1460s prints began to be incorporated in books, and illustrations became an increasingly important element for the marketing of books.

[54] Smith 2004: 27 (quote); Rossi 1970: ch. 1; Kavey 2007: ch. 2.
[55] Schäfer 2011: 2-5, 10-14, 259.
[56] Schmidt 2005: 40-43.

Nuremberg and Venice were the most important centres for the production of prints. Anton Koberger from Nuremberg, who happened to be Dürer's godfather, operated the largest prints firm of his time. Many of the early printmakers had been trained as wood-sculptors (woodcuts) or goldsmiths (engravings), and transferred their skills to the new art form. As a result of this 'convergence of skills, commercial circumstances, and an expanding audience', printmaking went through a series of rapid changes, all helping to make the product more realistic. Before the 1470s prints were almost always anonymously produced. During the stage of rapid innovations, the producers started to claim their personal contributions to the art. In Northern Europe Martin Schongauer in Colmar, and in Italy Andrea Mantegna from Venice were the most important innovators, before Dürer started to set new standards.[57]

Woodcuts were soon to be followed by engravings, and in the early sixteenth century by etchings. Engravings are cut out in copperplate. To print, the ink is spread across the whole plate. The untouched bits of the plate are then cleared again, so that the ink only stays in the cut-away grooves. Etchings are drawn in a coating on the copperplate, which is subsequently treated with acid, which affects only the areas where the coating has been removed by the artist. The rest of the procedure is similar to the engravings. Both techniques allow much more detail than wood and were therefore better suited for complex illustrations.[58] In the course of the fifteenth century printmakers became increasingly skilled in the presentation of complex realities, as can be seen in Dürer's work.

This increased quality of printed images was accompanied, and in certain areas even preceded, by the increased naturalism of painted works and sculptures. The single most important breakthrough was the invention of linear perspective. This is commonly dated to 1413, when the Italian architect Brunelleschi – he solved the problem of building the dome of the cathedral in Florence – made the first drawing using this novel technique. The drawing has not survived, but a letter associates his name with linear perspective. In the 1420s Masaccio already applied the technique to great effect in his famous Trinity fresco in the Sta. Maria Novella church in Florence. In 1435 Leon Battista Alberti

[57] Landau and Parshall 1994: 2-9 (quote from p. 5), 33, 38, 42, 51, 65.
[58] Stijnman 2012: ch. 1

recorded the technique in his *De Pictura*, which was published in the next year in a vernacular edition as *De Pittura*, dedicated to Brunelleschi. This is the first description in writing of linear perspective. As Alberti's work predates the invention of moveable type, it was still only accessible in manuscript form. Alberti, typically, was both an architect and an amateur painter, but at the same time a humanist scholar. He, for instance, also wrote the first Italian grammar. Lorenzo Ghiberti, who analysed linear perspective in his *Commentario* and applied the technique in bronze doors for the Florence Baptistery (c. 1435), was likewise a humanist scholar.[59]

Perspective allowed the producers of pictures to depict space in a realistic way by getting the proportions correct. It was an Italian invention and it took artists in other parts of Europe several decades to master the technique. Elsewhere, however, they were also developing their own techniques to achieve greater realism. Jan van Eyck, who originated from Holland but produced his famous works in Bruges, in the 1430s developed new mixtures of paint, as well as techniques to create realist effects. He was not the inventor of oil paint, but managed to make it do new things. When medieval painters wanted to show gold on their panels, they simply pasted gold-leaf in the right places. Van Eyck obtained a similar effect with paint.[60] The ways in which he captured the effects of light and thus managed to create the impression of mass in space (rather than covering a two-dimensional surface) helped to produce pictures that came much closer to observations of the eye than previous generations of painters had been able to do. Naturalism became to some extent a goal in its own right, especially in the Low Countries.[61] Italian commentators of the fifteenth century appreciated these Flemish contributions.[62]

Together, these changes amounted to a radical improvement in the techniques available to European craftsmen to provide realistic depictions of the world. Such techniques were developed in the arts, but could be deployed in various other industries. Most obviously the building industry profited from the new possibilities. Previously, most architectural designs had been life-size and *in situ* drawings of elements of the building. The best examples are found on the so-called tracing floors of building lodges,

[59] Kemp 1990: ch. 1.
[60] Nuttall 2004: 35; also Bol 2012.
[61] Alpers 1983
[62] Nuttall 2004, ch. 2.

floors that were used specifically for this purpose.[63] Other drawings – of which there are preciously few – provide impressions of (parts of) the façade. Only around 1500 do the first examples appear of a new type of drawings that were precise instructions to the builders, rather than impressions. This new type was in fact a combination of two drawings, which together told builders the dimensions of the construction. A projection from above gave the measurements of the ground plan, an attached view of the elevation showed in dimensions all the vertical parts. Dürer's Geometry (*Unterweissung der Messung*) from 1525 was a pioneering work in this field. Dürer applied the same principles to the construction of human figures on canvas.[64]

In technical drawings, the first major improvements were made during the fifteenth century by two Italian artists from Siena, Mariano di Jacopo, called Taccola (1381- ca.1453), and Francesco di Giorgio Martini (1439-1501), who went to work for the Dukes of Urbino. Taccola developed a pictorial convention that allowed the artist to depict the insides of various machines, by transparent and cutaway views. These pictorial inventions were then further improved by Martini, whose work was in turn shamelessly copied by the likes of Leonardo da Vinci.[65] All of their works were still only available in manuscript and therefore accessible to only a limited number of dedicated researchers and artists. This was to change in the sixteenth century, when woodcutters and engravers mastered the techniques to produce similar types of pictures for the illustration of technical treatises, such as Jacques Besson's *Théatre des instruments mathématiques et méchaniques* (Lyon, 1578) and Agostino Ramelli's *Le diverse et artificiose machines* (Paris, 1588). Like their fifteenth-century predecessors, these books did not so much depict working machines, as possible machines. They were, in other words, 'thought experiments', suggesting possibilities for technological development.[66] The point is, of course, that engineers were starting to use visual techniques to develop their ideas.

At the same time, constructions that might actually work were also transmitted on paper, either to serve as private archives, as presentation drawings for large (and expensive) projects, but also to share information within the community of

[63] Pacey 2007.
[64] Lefèvre 2004b.
[65] Edgerton 1991: 126-39; Long 2004.
[66] Edgerton 1991: 136 (quote), 148, 180-92; Popplow 2004: 24.

practitioners.[67] The building industry, as we saw, was one area where rapid progress was made. Machine-builders were served, not only by the works of Besson and Ramelli, but equally by Verantius and Zeising, who both published encyclopedic works on machines in the first decades of the seventeenth century. The emergence of special works for millwrights in the late seventeenth century, suggests a widening market with attendant specialization for technical literature, all of it lavishly illustrated. Such literature was not available, or at least not anywhere nearly as accessibly, for Chinese craftsmen.[68]

Manuals and the printing press

The invention of moveable type in the middle of the fifteenth century, and the first productions by Gutenberg, remained completely out of reach for the average artisan; the first Gutenberg bibles were priced at the equivalent of a year's wages. Very quickly, however, a steep fall in prices occurred, as the technique was improved and print runs increased, pushing down the marginal costs of books. By 1500 a book cost less than 40 percent of its manuscript equivalent, half a century later about twenty percent.[69] By now books had come within reach of ordinary people, including artisans. The drop in prices was accompanied by a rapid expansion in the number of titles and the topics covered by those titles. In 1480 Western-European booksellers together published 800 titles, in 1500 this had grown to 2,000 titles, and in 1600 it had reached 5,000.[70] Whereas Gutenberg had sensibly started out with the most popular European text, other publishers in later decades were willing to explore different types of demand, including craft manuals.

Pictures made books much more expensive. In works produced by Christopher Plantin, famous publisher in sixteenth-century Antwerp, illustrations, either as woodcuts or copper engravings, might add between two-thirds and three-quarters to the price of a book.[71] As a result, in architecture for instance, Sebastiano Serlio's treatises, published between 1537 and 1551, were only the first to be fully illustrated.[72]

[67] Popplow 2004: 28-42.
[68] Davids 2013a: 138-42, 189; Davids 2013b.
[69] Zanden 2009: 182-83.
[70] Zanden 2009: 184; Buringh and Van Zanden 2009.
[71] Kusukawa 2012: 53.
[72] Carpo 2001: 46.

Craftsmen also had easier access to printed texts because more of them were able to read. By the end of the eighteenth century at least fifty per cent of all adult males were able to sign their name and therefore presumably had basic reading skills. This covered the rural as well as the unskilled workforces, where literacy rates were notoriously low.[73] By implication, we must assume that by then the great majority of artisans was capable of reading more or less fluently and access complex texts about their own profession. Already in the sixteenth century literacy rates had been increasing rapidly in Italy, but it was overtaken in the seventeenth century by the Dutch Republic, which was well-known for its high literacy rates and equally for its outpouring of printed texts. In the seventeenth-century Netherlands, literacy, book production and technological innovation were all part of the magic mix of progress.[74]

Early works were preoccupied with a limited range of industries; in particular metallurgy, textile dyeing, distilling were popular topics for manuals.[75] In the sixteenth century that range was expanded, to include medicine, shipbuilding and the arts, for example. In the seventeenth century these were followed by such works as Joseph Moxon's *Mechanick Exercises: Or the Doctrine of Handy-Work, Applied to the Art of Tvrning* (1680).[76] In other words, an increasingly wide range of industries was covered by manuals. The percentage of titles devoted to 'science, technology and medicine' published in Britain increased from 5.5 to 9 during the eighteenth century.[77]

Conclusion

By 1500 European artisans had developed methods to produce naturalist pictures of more or less any object. They had also developed a vocabulary to capture some of their practices in words. Such pictures and texts had received the blessing of scholars, who often had been directly involved in their production. The printing press offered craft manuals at prices that were affordable to craft practitioners. Given the tacit character of craft skills, pictures and texts could never replace inter-personal training and first-hand

[73] Reis 2005: 200-208
[74] Davids 2008.
[75] Smith 2011: 52
[76] Cormack and Mazzio 2005: 83-85.
[77] Mokyr 2009: 46.

experience.[78] They could, however, help to develop such skills to new levels of quality and to stimulate innovation. Next to artisan mobility, printed texts and pictures created an international exchange of practices and examples.

It would take another couple of centuries before they became generally accessible. The establishment of drawing schools in late seventeenth and eighteenth-century Europe are an example of this consolidation, in that they made the results of the Renaissance development in visual expression available to large numbers of ordinary workmen.[79] Likewise, the fact that a run-of-the-mill stonemason's workshop in late eighteenth-century Rotterdam owned copies of Serlio's treatises on classical architecture from the sixteenth century, Bosboom and Danckers' interpretations of Scamozzi from the seventeenth century, as well as more recent works like *Vignoble moderne, ou Traité Elementaire d'Architecture* by Lucotte in an edition from 1777, demonstrates how widely available such material had become by then. Note also that this business library held a genuinely European range of works.[80]

Already before these changes in visual and textual practices emerged, European crafts had set themselves on a course that had at least the potential to promote quality through skills.[81] Beginning in the second half of the fourteenth century, and increasingly during the fifteenth, crafts required their prospective members to demonstrate their skill by producing a 'master-piece', as well as provide proof of an extended period of training. They continued to do so until they were disbanded in the wake of the French Revolution. By then, the changes set in motion during the fifteenth century had become routine elements of many craft practices.

These developments had a direct and indirect impact on the Industrial Revolution in three distinct ways.[82] First of all, the scope and quality of industrial goods available to European consumers increased markedly during the Renaissance and early modern period. This happened especially in the urbanised regions – Italy, Southern Germany, the Low Countries – but impacted far beyond those areas.[83] In many places the initial trigger

[78] Eamon 1994: 122.
[79] Puetz 1993; Thunder 2004; De Doncker 2013.
[80] Prak 2010: 54-55; compare Davids 2013a: 145.
[81] Cf. Davids 2013a: 227.
[82] For the role of craftsmen and their skills in the Industrial Revolution: Mokyr 2009: ch. 6
[83] Jardine 1996; De Vries 2008: ch. 1.

for such improved quality had been demand from courts and courtiers, i.e. from aristocratic circles. But a great many of their treasures became subsequently available in 'populuxe' varieties to the average consumer.[84] Cheap paintings and prints, produced by the millions in the Dutch Republic, are a case in point.[85] This, according to Jan de Vries, triggered an 'industrious revolution' that encouraged people to work more days and longer hours to be able to afford these new consumer goods, thus firing what others have termed the 'consumer revolution' of the seventeenth and eighteenth centuries.[86]

The second impact was during the Industrial Revolution itself. Margaret Jacob and Joel Mokyr in particular have emphasised the intimate connections between the worlds of science and of technology in eighteenth-century England.[87] From the perspective of the artisan 'revolution' one can only say that such connections went back a long way indeed in Europe. Robert Allen has, moreover, demonstrated that these types of networks were not universally available to the inventors of the Industrial Revolution. He does, however, underline apprenticeship as an important and almost universal element in the educational background of British inventors of the period. These people were also almost all literate and therefore had easy access to information stored in print.[88] It all goes to show that science and skill were much closer for a much longer period than has often been assumed.

The third impact came after the invention of the steam engine. Its relatively complex technology was exported to other regions of Europe without major problems. In those other regions, levels of skill and expertise were such that local craftsmen had little difficulty, after initial instruction, to use and maintain the imported machinery.[89] The rapid spread of steam technology was, it is suggested here, predicated on a geographically and socially broad diffusion of the type of skills necessary for the new industrial age.

---

[84] Fairchilds 1993.
[85] Woude 1991.
[86] De Vries 2008.
[87] Jacob 1997; Mokyr 2009: 42-43.
[88] Allen 2009: ch. 10.
[89] Mokyr 2009: 106,113 underlines how knowledge and technology were exchanged between Britain and the continent.

Bibliography

Allen, Robert C. (2009), *The British industrial revolution in global perspective* (Cambridge: Cambridge University Press)

Alpers, Svetlana (1983), *The art of describing: Dutch art in the seventeenth century* (Chicago: Chicago University Press)

Ames-Lewis, Francis (2000), *The intellectual life of the early Renaissance artist* (New Haven: Yale University Press)

Baer, Gabriel (1970), *Fellah and townsman in the Middle East: Studies in social history* (London: Frank Cass)

Blair, Ann M. (2010), *Too much to know: Managing scholarly information before the modern age* (New Haven: Yale University Press)

Bol, Marjolijn (2012), Oil and the Translucent: Varnishing and glazing in practice, recipes and historiography, 1100-1600, PhD-thesis Utrecht University

Buringh, Eltjo, and Jan Luiten van Zanden (2009), 'Charting the "rise of the West": Manuscripts and printed books in Europe, a long-term perspective from the sixth through the eighteenth centuries', *Journal of Economic History* 69: 410-46

Carpo, Mario (2001), *Architecture in the age of printing: Orality, writing, typography, and printed images in the history of architectural theory* (transl. By Sarah Benson) (Cambridge Ma.: MIT Press)

Cennini, Cennino d'Andrea (1954), *The craftman's handbook: The Italian 'Il Libro dell'Arte'*, translated by Daniel V. Thompson Jr. (New York: Dover Publications)

Cipolla, Carlo (1980), *Before the Industrial Revolution: European society and economy, 1000-1700* (New York: Norton, 2nd ed.)

Cormack, Bradin, and Carla Mazzio (2005), *Book use, book theory: 1510-1700* (Chicago: University of Chicago Library)

Crossgrove, William (1994), *Die Deutsche Sachliteratur des Mittelalters* Langs Germanistische Lehrbuch Sammlung, vol. 63 (Berne: Peter Lang)

Crowston, Clare (2005), 'L'apprentissage hors des corporations. Les formations professionnelles alternatives à Paris sous l'Ancien Régime', *Annales: Histoire, Sciences Sociales* 60: 409-442

Davids, Karel (2005), 'Craft secrecy in Europe in the early modern period: A comparative view', *Early Science and Medicine* 10: 341-48

— (2008), *The rise and decline of Dutch technological leadership: Technology, economy and culture in the Netherlands, 1350-1800* (Leiden: Brill)

— (2013a), *Religion, technology, and the great and little divergences: China and Europe compared, c. 700-1800* (Leiden: Brill)

— (2013b), 'Moving machine makers: Circulation of knowledge on machine-building in China and Europe between c. 1400 and the nineteenth century', in: Maarten Prak, Jan Luiten van Zanden (eds.), *Technology, skills and the pre-modern economy in the East and the West* Global Economic History Series, vol. 10 (Leiden: Brill), 205-24

De Doncker, Tim (2013), Hupsicheyt en hantgedaet: Kunstacademie en ambachtsgilden te Gent ca. 1748-1800 (unpublished PhD-thesis Universiteit Gent)

De Munck, Bert (2007), *Technologies of learning: Apprenticeship in Antwerp guilds from the 15th century to the end of the Ancien Régime* Studies in European Urban History, vol. 11 (Turnhout: Brepols)

— (2008), 'Skills, trust, and changing consumer preferences: The decline of Antwerp's craft guilds from the perspective of the product market, c.1500-c.1800', *International Review of Social History* 53: 197-233

—, Steven L. Kaplan, and Hugo Soly (eds.) (2007), *Learning on the shop floor: Historical perspectives on apprenticeship* (New York: Berghahn)

—, Piet Lourens and Jan Lucassen (2006), 'The establishment and distribution of craft guilds in the Low Countries, 1000-1800', in: Prak, Lis, Lucassen and Soly 2006: 32-73

—, and Hugo Soly (2007), '"Learning on the shop floor" in historical perspective', in: De Munck, Kaplan, and Soly 2007: 3-32.

de Vries, Jan (1984), *European urbanization, 1500-1800* (London: Methuen)

— (2001), 'Economic growth before and after the Industrial Revolution: A modest proposal', in: Maarten Prak (ed.), *Early modern capitalism: Economic and social change in Europe, 1400-1800* (London: Routledge), 177-94

— (2008), *The industrious revolution: Consumer behavior and the household economy, 1650 to the present* (Cambridge: Cambridge University Press)

Dürer, Albrecht (1977), *Four Books on Measurement* (*Unterweysung der Messung mit dem Zirckel und Richtscheyt* or *Instructions for Measuring with Compass and Ruler*), translated as *The Painter's manual*, ed. by Walter L. Strauss (Abaris Books)

— (2011), *Four Books on Human Proportion* (*Vier Bücher von Menschlicher Proportion*), ed. Berthold Hinz ([Berlin]: Akademie Verlag)

Eamon, William (1994), *Science and the secrets of nature: Books of secrets in medieval and early modern culture* (Princeton: Princeton University Press)

Edgerton Jr., Samuel Y. (1991), *The heritage of Giotto's geometry: Art and science on the eve of the Scientific Revolution* (Ithaca: Cornell University Press)

Eichler, Anja (2007), *Albrecht Dürer* (Potsdam: H.F. Ullmann)

Epstein, Steven A. (1991), *Wage labor and guilds in medieval Europe* (Chapel Hill NC: University of North Carolina Press)

Epstein, S.R. (1998), 'Craft guilds, apprenticeship and technological change in pre-modern Europe', *The Journal of Economic History* 53: 684-713 (reprinted in Epstein and Prak 2008)

—, and Maarten Prak (eds.) (2008), *Guilds, innovation and the European economy, 1400-1800* (Cambridge: Cambridge University Press)

Fairchilds, Cissie (1993), 'The production and marketing of populuxe goods in eighteenth-century Paris', in: John Brewer and Roy Porter (eds.), *Consumption and the world of goods* (London: Routledge), 228-248

Gelderblom, Oscar, and Regina Grafe (2010), 'The rise and fall of the merchant guilds: Re-thinking the comparative study of commercial institutions in premodern Europe', *Journal of Interdisciplinary History* 40: 477-511

Ghazaleh, Pascale (1999), *Masters of the trade: Crafts and craftspeople in Cairo, 1750-1850* (Cairo: American University in Cairo Press)

Golahny, Amy (2003), *Rembrandt's reading: The artist's bookshelf of ancient poetry and history* (Amsterdam: Amsterdam University Press)

Hess, Daniel, and Thomas Eser (eds.) (2012), *The early Dürer* Exhibition catalogue Germanisches Nationalmuseum Nuremberg 2012 (London: Thames & Hudson)

Humphries, Jane (2010), *Childhood and child labour in the British Industrial Revolution* (Cambridge: Cambridge University Press)

Hutchison, Jane Campbell (1990), *Albrecht Dürer: A biography* (Princeton: Princeton University Press)

— (2000), *Albrecht Dürer: A guide to research* (Artist Resource Manuals) (New York: Garland)

Jardine, Lisa (1996), *Worldly goods: A new history of the Renaissance* (New York: Norton)

Kaplan, S.L. (1993), 'l'Apprentissage au XVIIIe siècle : Le cas de Paris', *Revue d'histoire moderne et contemporaine* 40: 436-79

Kaufmann, Thomas DaCosta (1975), 'The perspective of shadows: The history of shadow projection', *Journal of the Warburg and Courtauld Institutes* 38: 258-87

Kavey, Allison (2007), *Books of secrets: Natural philosophy in England, 1550-1600* (Urbana Ill.: University of Illinois Press)

Kemp, Martin (1990), *The science of art: Optical themes in western art from Brunelleschi to Seurat* (New Haven: Yale University Press)

Kluge, Arnd (2009), *Die Zünfte* (Stuttgart: Franz Steiner)

Kusukawa, Sachiko (2012), *Picturing the book of nature: Image, text, and argument in sixteenth-century human anatomy and medical botany* (Chicago: University of Chicago Press)

Landau, David, and Peter Parshall (1994), *The Renaissance print 1470-1550* (New Haven: Yale University Press)

Lefèvre, Wolfgang (ed.) (2004a), *Picturing machines 1400-1700* (Cambridge Ma.: MIT Press)

— (2004b), 'The emergence of combined orthographic projections', in: Lefèvre 2004a: 209-244.

Long, Pamela O. (1997), 'Power, patronage, and the authorship of Ars: From mechanical know-how to mechanical knowledge in the last scribal age', *Isis* 88: 1-41

— (2001), *Openness, secrecy, authorship: Technical arts and the culture of knowledge from Antiquity to the Renaissance* (Baltimore: Johns Hopkins University Press)

— (2004), 'Picturing the machine: Francesco di Giorgio and Leonardo da Vinci in the 1490s', in: Lefèvre 2004a, 117-41

Mokyr, Joel (2002), *The Gifts of Athena: Historical origins of the knowledge economy* (Princeton: Princeton University Press)

— (2009), *The Enlightened economy: An economic history of Britain 1700-1850* (New Haven: Yale University Press)

Moll-Murata, Christine (2008), 'Chinese guilds from the seventeenth to the twentieth century: An overview', in: Jan Lucassen, Tine De Moor, Jan Luiten van Zanden (eds.), *The return of the guilds* (Cambridge: Cambridge University Press; also published as *International Review of Social History Supplement*), 213-47

Nuttall, Paula, *From Flanders to Florence: The impact of Netherlandish painting, 1400-1500* (New Haven: Yale University Press)

Pacey, Arnold (2007), *Medieval architectural drawing: English craftsmen's methods and their later persistence (*c.*1200-1700)* (Stroud: Tempus)

Popplow, Marcus (2004), 'Why draw pictures of machines? The social context of early modern machine drawings', in: Lefèvre 2004a: 17-48

Prak, Maarten, 'The market for architecture in Holland, 1500-1815', in: Laura Cruz, Joel Mokyr (eds.), *The birth of modern Europe: Culture and economy, 1400-1800. Essays in honor of Jan de Vries* (Leiden: Brill), 35-59

— (2011), 'Mega-structures of the Middle Ages: The construction of religious buildings in Europe and Asia, c. 1000-1500', *Journal of Global History* 6: 381-406.

—, Catharina Lis, Jan Lucassen and Hugo Soly (eds.) (2006), *Craft guilds in the early modern Low Countries: Work, power, and representation* (Aldershot: Ashgate)

Puetz, Anne (1993), 'Design instruction for artisans in eighteenth-century Britain', *Journal of Design History* 12: 217-39

Reis, Jaime (2005), 'Economic growth, human capital formation and consumption in western Europe before 1800', in: R.C. Allen, T. Bengtsson and M. Dribe (eds.), *Living standards in the past* (Oxford: Oxford University Press), 195-227

Rossi, Paolo (1970, *Philosophy, technology and the arts in the early modern era* (New York: Harper & Row; Italian orig. 1962)

Ruurs, Rob (1987), *Saenredam: The art of perspective* (Amsterdam: Benjamins)

Schäfer, Dagmar (2011), *The crafting of the 10,000 things: Knowledge and technology in seventeenth-century China* (Chicago: University of Chicago Press)

Schmid, Wolfgang (2003), *Dürer als Unternehmer: Kunst, Humanismus und Ökonomie in Nürnberg um 1500* Beiträge zur Landes- und Kulturgeschichte vol. 1 (Trier: Porta Alba)

Schmidt, Peter (2005), 'The beginnings of printmaking, between old theories and new approaches', in: Peter Parshall, Rainer Schoch (eds.), *Origins of European printmaking:*

Fifteenth-century woodcuts and their public Exhib. catalogue National Gallery of Art Washington, Germanisches Nationalmuseum Nuremberg, 37-56.

Shelby, Lon, and Robert Mark (1979), 'Late Gothic design in the "Instructions" of Lorenz Lechler', *Architectura* 9: 113-131

Smith, Pamela H. (2004), *The body of the artisan: Art and experience in the Scientific Revolution* (Chicago: University of Chicago Press)

— (2009), 'Science in Motion: Recent Trends in the History of Early Modern Science', *Renaissance Quarterly* 62: 345-375

— (2010),'Why Write a Book? From Lived Experience to the Written Word in Early Modern Europe', *Bulletin of the German Historical Institute*, 47: 25-50

— (2011), 'What is a secret? Secrets and craft knowledge in early modern Europe', in: Elaine Leong and Alisha Rankin (eds.), *Secrets and Knowledge in Medicine and Science, 1500-1800* (Farnham: Ashgate), 47-66

— (2012), 'In the workshop of history: Making, writing, and meaning', *West 86th*: 4-31

Stijnman, Ad (2012), *Engraving and etching 1400-2000: A history of the development of manual intaglio printmaking processes* (London: Archetype Publications)

Thunder, Moira (2004), 'Improving design for woven silks: The contribution of William Shipley's school and the Society of Arts', *Journal of Design History* 17: 5-27

Van den Heuvel, N.H.L. (1946a), *De ambachtsgilden van 's-Hertogenbosch vóór 1629: Rechtsbronnen van het bedrijfsleven en het gildewezen* (Utrecht: Kemink en Zoon)

— (1946b), *De ambachtsgilden van 's-Hertogenbosch vóór 1629* ('s-Hertogenbosch: Adr. Heinen)

Van Netten, Djoeke (2013), *Koopman in kennis: De uitgever Willem Jansz Blaeu en de geleerde wereld van zijn tijd (1571-638)* (Zutphen: Walburg Pers)

Van Zanden, Jan Luiten (2009), *The long road to the Industrial Revolution: The European economy in a global perspective, 1000-1800* Global Economic History Series, vol. 1 (Leiden: Brill)

Wallis, Patrick (2008), 'Apprenticeship and training in pre-modern England', *Journal of Economic History* 68: 832-861

Wolf, Norbert (2010), *Albrecht Dürer* (Munich: Prestel)

Woude, Ad van der (1991), 'The volume and value of paintings in Holland at the time of the Dutch Republic', in: David Freedberg and Jan de Vries (eds.), *Art in history, history in art: Studies in seventeenth-century Dutch culture* (Santa Monica: Getty Center for the History of Art and the Humanities), 285-329

Yi, Eunjeong (2004), *Guild dynamics in seventeenth-century Istanbul: Fluidity and leverage* (Leiden: Brill)