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# *The economic revolution in book design that went unnoticed: changing paper thickness in folios, quartos and octavos. The case of the Southern Netherlands, 1473-c. 1550*

## 1. Radical changes in book production

The introduction in the West by Joannes Gutenberg (c. 1400? †1468; Bechtel 1992, 16) of printing with moveable type prompted a radical change in the production, distribution, and consumption of printed objects, not least of books. Once the "black art" had been made perfect and had been ran in, one press could print one sheet on both sides (inner and outer forme) in one colour (black) per day on extensive printruns. Gutenberg's 42-line Bible was probably printed on a run of about 158 to 180 copies (White 2017). In general, scholars maintain the number 500 for a typical fifteenth-century printrun (Schweitzer-Martin 2022, 152). As far as this is documented, printruns in the Southern Netherlands in the fifteenth century ranged between 100 and 300 copies (Adam 2018, I, 110-111). In the sixteenth century printruns increased to 1,250 copies and more (Imhof 2014, I, LXXXII). It goes without saying that those production times are incomparable with those of manuscripts. By way of example, one could cite one of the copies of the *Elsässissche Legenda aurea*, a large folio written in cursive script (which was probably not as slow as the most formal scripts), kept in the Bibliothek des Priesterseminars, Rottenburg (Cod. 11).[1] The production of the second part only of this extensive text took seven months, from Advent 1463 until 24 July 1464, which comes down to four pages in three days (Williams-Krapp 2019, 65). In that time, a press would produce four times as many pages (12 pages in folio, or three printing sheets recto and verso). Moreover, this would not result in a single copy, but in several hundreds of them – a multiplication in speed by a factor 1,000 and over.

Gutenberg tried to keep the tools and techniques he had developed secret for his competitors, hoping to capitalize on his investments first, and to reimburse his backers. After a court case, Gutenbergs fincancial backer and business partner Johann Fust started his own printing shop (Füssel 2019, 43), and the «art of writing artificially» started to spread, first in Mainz, then in the wider region, subsequently travelling to some 300 different cities and towns all over Europe (Sordet 2021, 199). By the end of the fifteenth century several hundreds of printing shops had

[1] I would like to thank prof. dr. Werner Williams-Krapp, Augsburg, for this reference.

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produced more than 32,000 editions of books, not to speak of a vast number – and for the major part unrecorded – ephemera.[2]

Now that the problem of printing books in series was solved, a new one was waiting for a solution. As a rule, in the 'manuscript era' books were ordered first and copied out for clients subsequently. That way, production and distribution were covered from the outset. But in the 'handpress era', the new logic required that printers and publishers produced large numbers of copies for yet unknown customers. This required the development of networks and methods to inform potential buyers of the existence of books they actually had never really asked for. In the beginning, printers and publishers sometimes had to leave their workshops in search for customers (Conway 1999, 55, 57). Soon they began to advertise for their products and started to use the existing trade infrastructure and went to fairs (Coppens 2014).

## 2. Paper and price

While the public was being informed about the availability of books, and printers and publishers had found ways to cater them to potential buyers, still there were other difficulties to overcome. Two of them are closely connected: one is paper, another one price.

Compared to scriptoria and workshops where books were copied out by hand, shops running printing presses needed much larger quantities of writing supports. During the 'printing era', the major part of the copies was produced on paper and only a fraction still on parchment, mostly for very specific reasons. Culturally, paper had increasingly being accepted as a worthy alternative for parchment. At the latest since the last quarter of the fourteenth century, most books had been produced on paper (Schweitzer-Martin 2022, 150). In this respect, price was a first important factor. As the accounts of the city of Basel indicate, between 1402 and 1500, the price of paper dropped by about 50%, whereas the price of a hide remained more or less stable. In 1401 one hide cost the equivalent of 30 to 40 sheets of paper. In 1500, one could buy 72 to 116 sheets of paper for the price of one hide (Kälin 1974, 77). But even so, it remains a fact that in the first decades of printing paper was the greatest expense in printing (Conway 1999, 16). Also in the sixteenth century, paper remained the major cost. In Christoph Plantin's days, «[...] paper accounted for an average of 60-65 per cent of the cost of producing a book [...]» (Voet 1969-1972, II, 19). In terms of cost, paper was followed by wages (Voet 1969-1972, II, 382-384, 467).

Availability was a second factor. Parchment has always been a by-product of the food industry, which bred animals for diary and meat in the first place. As a rule, animals were slaughtered in function of that purpose, after which their hides would serve to make leather and parchment. The quantities available could never be sufficient to cover the needs of large printruns of extensive books (Schweitzer-Martin 2022, ch. 5). Paul Schweitzer-Martin has calculated that the four printshops

[2] Numbers for editions derived from the Universal Short Title Catalogue (www.ustc.ac.uk) on 3 April 2022.

active in Speyer between 1471 and 1500 used about 6 million sheets of paper to print in total some 300 different editions on an estimated printrun of 500 copies per edition (Schweitzer-Martin 2022, 152). This number clearly illustrates the importance of paper supply and the sudden upsurge in demand caused by the developping printing industry.

## 3. Paper thickness[3]

In this contribution, I will discuss the evolution of paper thickness of books produced in the Southern Netherlands in the period 1473 until the middle of the sixteenth century. As I will argue, changing paper thickness is one of the key elements which in all likelihood helped coping with the problem of the rapidly increasing demand for paper by the press.

Although most scholars are aware of the fact that incunabula (as books printed in the fifteenth century are called) are printed on thick paper, there is only a handfull of studies looking into this matter. It is as if anyone has ever asked the question when printers stopped using thick paper, and neither can one find in literature a definition of "thick paper". In the chapter about paper in the recently published standard work *Grundriss der Inkunabelkunde* by Wolfgang Schmitz, paper thickness is not discussed (Schmitz 2018). The chapter in question contains references to two articles by Holger Nickel from 1976 and 1980. In the 1976 article, Nickel alludes to the introduction of thinner paper: «Das Buchformat konnte nicht verkleinert werden, auch Papiersorten von geringerer Stärke verringerten den Umfang der Bände» (Nickel 1976, 484). And although he acknowledges that at a given moment books became smaller as a result of the use of thinner paper, Nickel does not go into the question when or how this happened. Four years later, Nickel makes in passing a link between the use of new sorts of paper and books becoming cheaper: «Neue Papiersorten verbilligten die Bücher, so daß ein Interessent für das gleiche Geld immer dickleibigere Werke kaufen konnte» (Nickel 1980, 322). But other than making a reference to Piccard (1967), the author remains silent.

Until recently, only a few scholars published on the topic. Two Swiss scholars jointly devoted two brief articles on the matter. The subject is also discussed in the two-volume publication of the research project *Il progetto carta*. Paper thickness is also studied by the team directed by Timothy Barrett in the context of a broader survey of handlaid paper from the fourteenth until the nineteenth century.

In a first article from 1992, Utter and Utter published a theory explaining the variation in thickness of handlaid sheets (Utter and Utter 1992). They argue that during the cyclus of making one post of paper (181 sheets), the pulp concentration in the vat gradually becomes thinner, which is reflected in thinner sheets. In addition, they identify the height of the deckle as a second factor of influence on the thickness of the sheets. Both elements have also been named by J.J.F. de la Lande in 1761, but those are not the only two relevant factors. In a comment following the article, Peter F. Tschudin rightly points out that the skill and experience of the

[3] Sections 3-6 are based on Proot 2021b.

vatman are also of great importance for the manufacture of sheets with the same weight, a viewpoint endorsed by Timothy D. Barrett (2018, 105).

In a second article, the Swiss authors discuss the variation in thickness within the handlaid sheet (Utter and Utter 1994). First, they establish that paper thickness and weight are correlated – a fact of importance for the survey discussed below in this contribution. Furthermore, they show that the handlaid sheet has thicker and thinner areas along both the short and the long edge, and that the paper is thicker on chainlines than between them. In order to make a good estimation of its thickness, they propose to measure sheets on six points (Fig. 1). The suggestion to measure different points is also made by other authors (cf. infra). Diagrams 9 and 10 in their article refer to waves in the sheet, one parallel with the short edge and the other one with the long edge (see Figures 2 and 3). Utter and Utter do not explain where these waves come from. I will come back to this later.

Fig. 1. **Six points proposed by Utter & Utter 1994, 43 (Fig. 5) to measure the thickness of a sheet of paper**

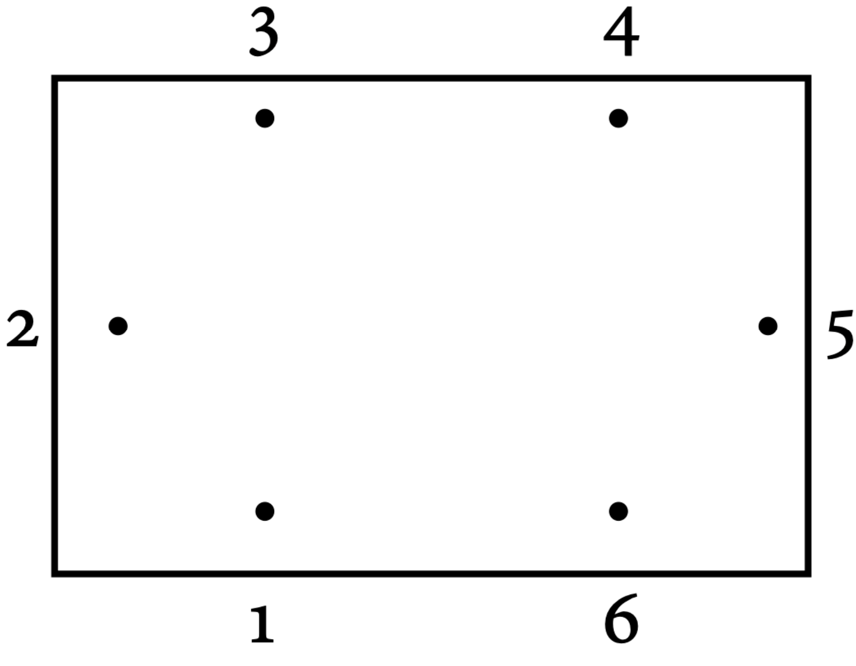


Fig. 2. **Wave detected by Utter & Utter 1994, 43 (Fig. 9) in the upper and lower long edges of a sheet of paper. The abbreviation «St». (German: «Steg») indicates the position of the ribs of the mould**

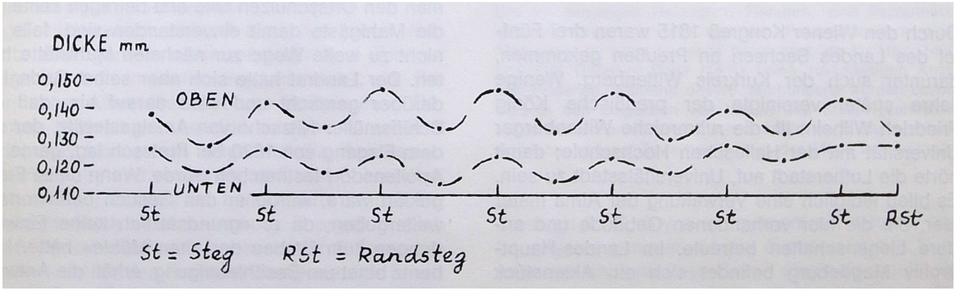
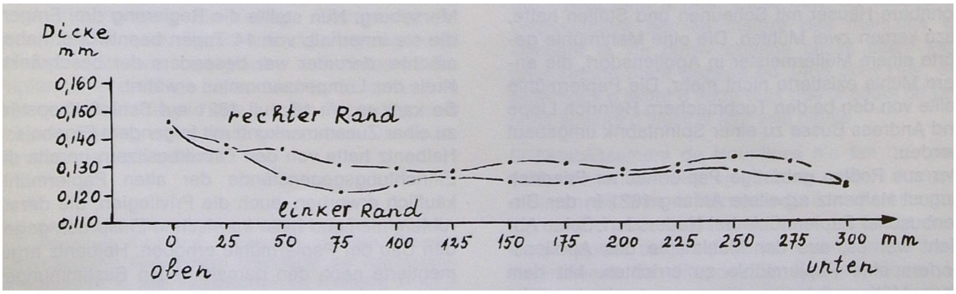
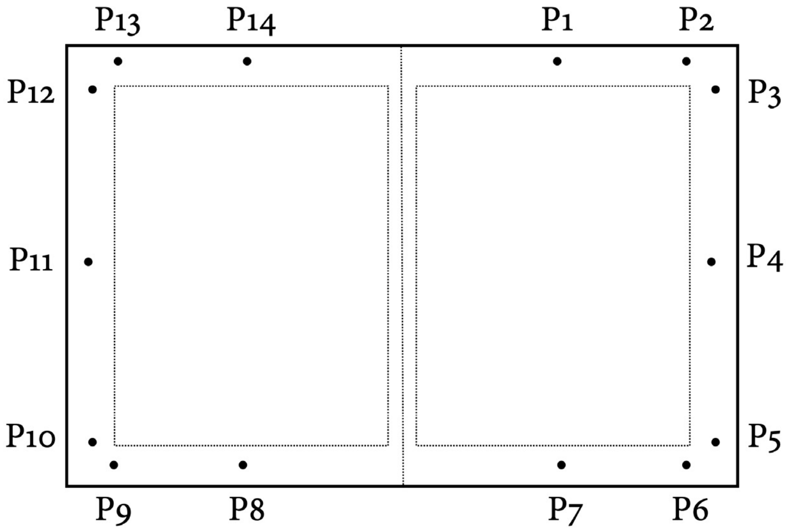



Fig. 3. **Wave detected by Utter & Utter 1994, 43 (Fig. 10) in the left and right short edges of a sheet of paper. «Rechter Rand» refers to the right edge, «linker Rand» to the left edge of the mould**



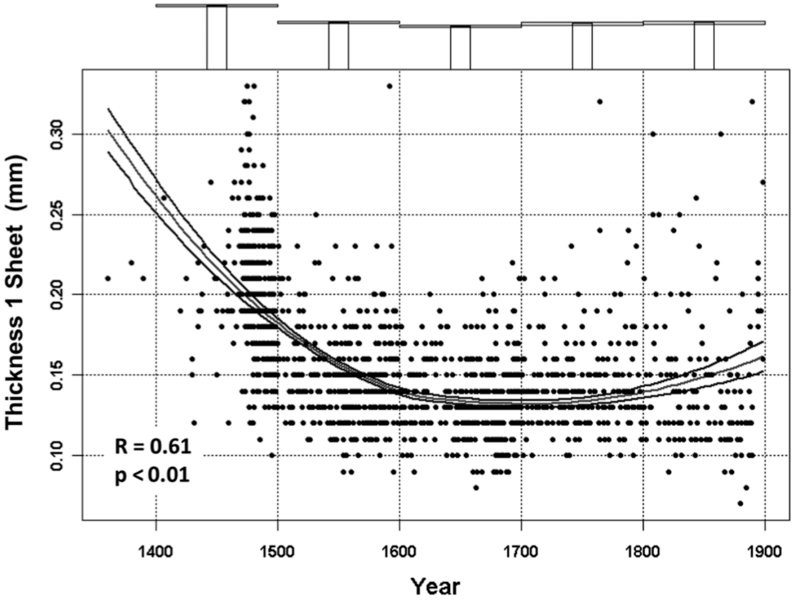

The researchers of *Il progetto carta* published two volumes on the late-medieval paper and about incunabula (Ornato et al. 2001). They discuss, amongst other things, different formats, the colour (whiteness) of paper and its thickness. Their point of departure is that the sheet is a three-dimensional structure with two flat faces. They measure the thickness of sheets on 14 different points, which usually return 14 different values (Ornato et al. 2001, I, 44; Fig. 4). They argue that these differences are (in part) the result of a certain degree of *grumosità*, impurities in the pulp caused by coagulation of fibres: «La grumosità della carta medievale – e più in generale le impurità in essa presenti – non ha suscitato un enorme interesse presso gli storici del manufatto. Solo Dard Hunter – che le definisce peppered appearance – ne indica brevemente le cause: i grumi sono dovuti all'intrecciarsi delle fibre di cellulosa nella sospensione» (Ornato et al. 2001, II, 103). Whereas the values between points which lay close to each other show positive correlations, points between which there is a great distance, show negative correlations. This observation is left without further explanation (*ibidem*).

Fig. 4. **Location of the fourteen measuring points on a sheet of paper used by Ornato et al. 2001 (I, 44)**




In their survey *Non-destructive analysis of 14th-19th century European handmade papers*, Barrett, Ormsby and Lang try to figure out how handlaid paper changed in the course of five centuries. For this purpose, they studied the quality of 1,578 historical samples of European sheets. In addition to colour (whiteness), their focus is on sizing practices with gelatine (Barrett et al. 2016). With several sophisticated measuring tools, they are able to trace elements such as calcium and iron in the paper. Iron is linked to a darker paper colour and has its origin in polluted water used during the production. This metal has a negative impact on the paper quality. Furthermore, the researchers have found that the quantity of gelatine for sizing is reduced significantly in the sixteenth century compared to the fifteenth century. At the same time, they find that paper gradually becomes thinner, an observation which is confirmed through the use of a micrometer with a presicion of 0.01 mm (Barrett et al. 2016, 106-108). In order to cope with the «natural variation in paper thickness in a single book», the scholars measure ten subsequent leaves (Barrett et al. 2016, 103), a phenomenon of which Barrett, who is a papermaker himself, is very well aware. In this study, neither the origin of this variation is explained, nor is the measuring methodology discussed in detail. We can only assume that all different bibliographical formats were treated in the same way. Graph 10 in this study is a scatter plot showing the paper thickness of individual sheets, along with a regression line. The scatter plot in Graph 11 is based on values for 10 sheets. (See Figures 5 and 6.) The regression line shows values which are systematically lower than those on Graph 10, a difference which remains unexplained. Based on our own research (Proot 2021b), we gather that the difference is due to the so-called compression effect (cf. infra).

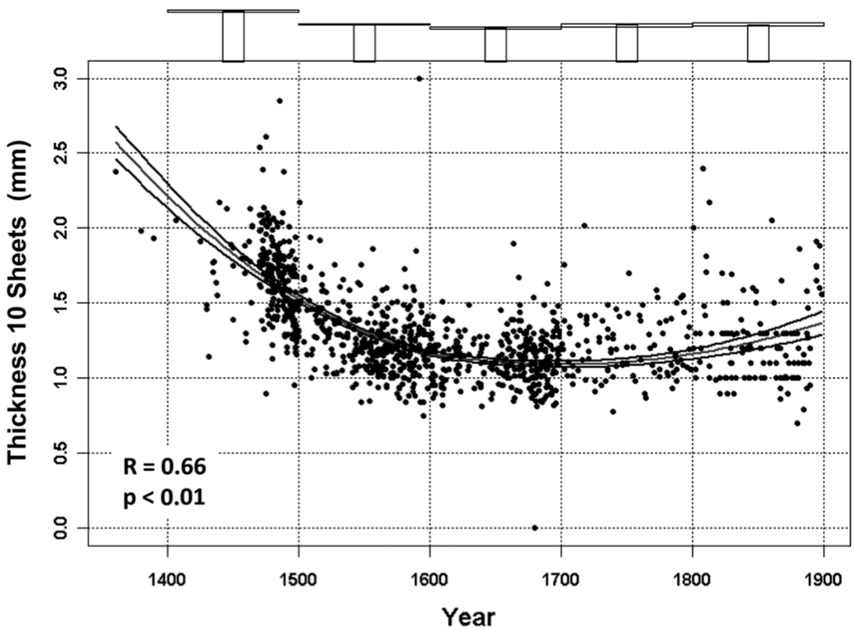
Fig. 5. **Graph 10 taken from Barrett et al. 2016, 107**




Note: «The thickness of specimens is shown according to year [...]. The discrete levels in the vertical axis result from the minimum increments on the micrometer. The decrease in thickness was statistically significant over the first three periods in the tabletop plot».

Barrett and his colleagues suggest that the first printers consciously used papers with a structure, colour and dimensions emulating parchment (Barrett et al. 2016, 110-111). By doing so, they probably aimed at creating objects with a look and feel close to traditional books (compare Proot 2017, 21-22). For the productions of thick sheets mills required much pulp, what has a direct impact on the price. Papermakers lowered the price of paper by making it thinner and by using less sizing. Curiously, the researchers also link thicker paper with lower quality (Barrett et al. 2016, 118-119), which they explain by a faster production of the pulp. I find this a puzzling statement; probably there are other elements involved.

Fig. 6. **Graph 11 taken from Barrett et al. 2016, 108**




Note: «The discrete micrometer increments are less apparent in this plot of the thickness of the specimen together with the following 9 sheets in the book. [...] The tabletop confidence intervals indicate a statistically significant decrease in thickness over the first three periods». The authors do not explain the difference in thickness between Graph 10 and Graph 11. Based on Graph 10, one would for instance expect that the regression lines at 1500 would intersect at a value somewhere between 1.6 and 1.8 mm for 10 leaves, but the average value is lower.

Five years ago, I started measuring paper thickness of early modern books from the Southern Netherlands in the context of an exhibition about typographical features of incunabula and postincunabula (Proot 2017). Two years later, I continued this research together with prof. dr. Wolfgang Jacquet, a Belgian statistician (Vrije Universiteit Brussel), and dr. Paul Schweitzer-Martin, a German book historian (University of Munich). Much of the findings presented here below are the result of our discussions and try and error.

## 4. Relevant aspects of the handlaid-paper production in the West

It is not a simple task to establish the thickness of handlaid paper produced in the handpress era. In contrast to modern, machine-made paper, the morphology of handlaid paper is not plane but fairly complex. A better understanding of the morphology requires a discussion of the raw material to produce paper, the construction of the mould, paper making and wholesale practices.

For about eight centuries, the process of paper making in Europe basically remained unchanged (Loeber 1982, 4-5). Handlaid paper, that was made in Spain from the eleventh century and not much later in Italy and elsewhere on the continent, is a by-product of clothes and fabrics, which were woven with natural, celluloid-rich fibers of vegetal origin (Loeber 1982, 4). For the production of paper served mainly hemp and linnen, but also other fibers were used, such as cotton (Barrett 2018, 4-28). The raw materials were collected by old-cloths-men and then sorted according to quality. Buttons and other foreign elements were removed from the rags, which were then cut to pieces and washed. Then the rags were soaked and underwent retting (fermentation or putrefaction). To reduce the loss of fiber during this process, quicklime or chalk could be added to the mix. This also added an alkaline reserve to the resulting paper, which had a positive effect on its preservation (Schmitz 71; comp. Barrett 2018, 25). After these chemical processes the stuff was subsequently further reduced mechanically by water-wheel powered stamper beaters to individual, softened, cellulose fibers. Constant washing also bleached and plasticized the fiber (fibrillation). As a result, fine fibrils raised from the main fiber surface (Barrett 2018, 24), which later on advanced the 'closing' of the sheet during the papermaking process. The resulting stuff was mixed with water in a vat. Any impurities in the stuff result in impurities in the paper, such as coagulating stuff and knots, in Italian also called «grumosità» (Ornato et al. 2001, II, 103), which can easily detected by holding up the paper against the light or by measuring thickness. In my experience, such bulges and swellings in the paper appear quite often in fifteenth-century paper used to print books in the Southern Netherlands, and much less so in copies produced later. This suggests that production methods may have been refined gradually. Between 1650 and 1680, the Dutch developed the so-called «Holländer», a wind-powered machine which reduced rags to fibrillated fibers (Barrett 2018, 25-27). The use of this machine no longer required preparatory retting.

In Europe, a rigid mould with a wire cover was introduced around 1250 and remained in use until the end of the modern era. It consisted of a rectangular frame the long sides of which were connected by ribs running parallel to the short sides about one inch apart (Loeber 1982, 5). Thin metal wires (until around 1700 usually made of copper) were stretched above the ribs. These lines are known as chain lines. One extra wire was added on both sides of the frame to strenghten the construction. These lines are called «tranchefiles», also known as «water-bar lines», «water-bar wires» or «suction-bars» (Gaskell 2006, 61; Loeber 1982, 41; Labarre 1952, 327, s.v. *water-bar*). Placed on top of chain lines and tranchefiles, and perpendicular to them, are the so-called wire lines, metal bars with a gauge of about 0.65 mm standing about 0.35 mm apart (Loeber 1982, 20). This construction forms a sieve holding the stuff from the vat while the water runs through it. From the late thirteenth century, mould-makers sew a thin metal figure made of a thin copper or silver wire onto the mould covering, leaving a watermark in the paper. In the handpress era, watermarks can usely be spotted in the middle of the upper or lower half of the sheet when held portrait-wise against the light. In the middle of the other half often appears, from the late fifteenth century, a secondary mark or so-called «countermark», which becomes more frequent from the sixteenth century (Loeber 1982, 49; Labarre 1952, 60, s.v. *countermark*).

For making paper, the vatman places a deckle on top of the mould, which prevents the water and stuff from running off the sides of the mould (Labarre 1952, 70, s.v. *deckle*). It is the dimensions of the deckle which define the height and width of the sheet, and which, to a certain extent, help to make thinner or thicker paper. But in the end, it is the experienced vatman who will define the thickness of the paper by taking on extra stuff onto the mould or throwing off excess stuff during the papermaking process. Stuff piling up against the edges of deckle will result in the characteristic irregular and thicker «deckle edges» of the handlaid sheet.

The quality of the paper depends to a great extent on all the steps preceding the actual sheet forming. But the work of the vatman, the coacher, and the layer, too, are essential and can leave unwanted traces on the final product if they do not perform well. The vatman puts the deckle on top of the mould, which he holds with his hands on the short edges, with the long sides parallel to his chest. Then he dips the mould into the vat, brings it up, and then controlls the weight by throwing off or taking on stuff. As de la Lande described in 1761 with great precision, the vatman distributes the stuff evenly on the mould by shaking it with controled gestures from left to right and from right to left («*promener*»), and then in the other direction, pushing it away from him and pulling it back to him («*serrer*»). Finally, the sheet is "closed" with a specific shake («[...] *enverger la feuille, c'est-à-dire, à la fixer & à l'arrêter*», cf. de la Lande 1761, §125), binding and fixing the fibers drifting about in all directions, which solidifies the structure. During these movements, the water runs through the sieve. The ribs of the mould accelerate the evacuation of the water, locally causing minuscule heaps of pulp, resulting in 'shadows' parallel to the chainlines when looking at the sheet against the light (de la Lande 1761, §84). These 'waves' of thinner zones in between chainlines and thicker zones immediately next to the chainlines have been described by Utter and Utter (1994). After the closing of the sheet, the vatman removed the deckle, pushed the mould to the coucher, and repeated all actions with a second, nearly identical mould (the so-called twin) to form a second sheet.

The coucher transferred the sheet from the first mould onto a damp woolen felt with a rolling motion. This action results in a rough mould side of the sheet, which is marked by the metal wires pressing into the waterleaf sheet, and a so-called smoother felt side. The difference can often easily be sensed or visually detected with raking light. The sheet is then covered by a second felt, on which is couched the following sheet and so on, until a 'post' of felts and sheets is ready to be pressed under a massive wooden press for further dewatering (Barrett 2018, 31). When the post is dry enough, the layer cautiously strips the still vulnerable sheets from the felts for further drying and repeated pressing in smaller packs, an operation adding more smoothness to the surfaces of the sheets (Barrett 2018, 32). Afterwards, the sheets were taken to the drying room, where 'spurs' of three to eight sheets at once were hung over horsehair or cow's hair ropes coated with beeswax (Barrett 2018, 32). Sometimes, the ropes left a folding trace in the middle of the sheet. During the drying process, the paper shrank, depending on the season, up to 4% in length and 2% in width (Loeber 1982, 41). Drying was followed by sizing, which in Europe from the fourteenth century was usually done with gelatine. Without this treatment the sheets reacted as blotting paper. In addition, gelatine also added considerably to the strenght of the sheets. Hereafter, the paper had to dry again and was then flattened and polished on a marble stone or hammered on an iron plate. Around the middle of the eighteenth century, sometimes calenders were used to flatten the sheets (de la Lande 1761, §117).

After a quality control, the paper was packed for the wholesale market in reams (units of 500 sheets) and bales (10 reams). In retail, paper was sold per hand (24 or 25 sheets). Each sort was defined by its dimensions and minimum weight, which was set per ream (de la Lande 1761, §115). Fluctuations in weight were tolerated, but always between well established limits. Sheets which did not meet the standards were discarded during the production process, which contributed to a certain degree of homegeneity among paper of a specific quality. For printing, paper has to have a minimum thickness and strenght in order to prevent type piercing through the sheet. In addition, paper had to be opaque enough so that the printing on the verso would not bleed through and disturb reading. In some areas paper for the printing industry remained unsized until after printing, but this was not the case in the Southern Netherlands. In the incunabula period, however, gelatine levels for sizing printing paper were lowered to make it easier to print on (Barrett et al. 2016, 110-111). Incidentally, this also reduced the production cost of paper.

## 5. The morphology of handlaid paper

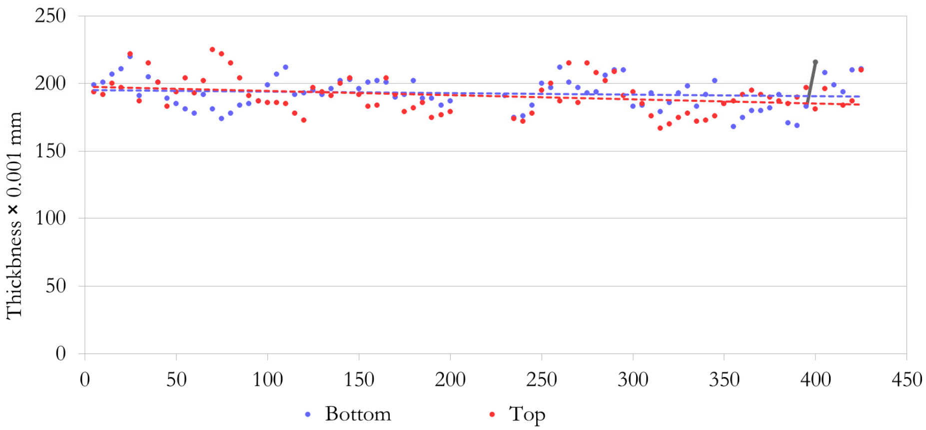
Each handlaid sheet of paper is unique as a result of the composition of the pulp, the characteristics of the mould, and the different stages of the actual papermaking process carried out by the different agents involved. In contrast to modern machine paper, handlaid paper has no direction in which it feeds, and neither it is perfectly plane. Handlaid paper has the structure of an egg carton, or of two intersecting chains of mountains and valleys, one of which runs parallel to the short edge and the other one parallel to the long edge of the sheet. This results from the *promener* and *serrer* of the vatman, movements generating two so-called perpendicular standing waves, now neutralizing and then amplifying each other. Some scholars have indicated the hills and dales running parallel to the chainlines (the short edge of the mould; Tschudin 2002, 51-52), but if one looks closely at a handlaid sheet against the light, it is obvious that there are also hills and dales running running paralled to the waterlines, so perpendicular to those running parallel to the chainlines.

In addition, sheets are usually slant in two dimensions, in height as well as in width. The near side of the mould, closest to the vatman's body, is usually thicker, because he usually holds the mould at an angle with the far side up. As a result, the pulp slightly accumulates at the near side. But in the other dimension, one side is also thicker than the other one. This is linked with the fact that everyone has a dominant arm, which naturally carries more wheight than the other one. As a result, the pulp naturally flows down from one side to the other one.

Both phenomena, of the intersecting mountains and valleys, and of the slant in two directions, can be detected through measuring handlaid sheets with a precision instrument (Graph 1).

At any stage the papermaking process, mistakes will also leave their traces in the structure of the sheet. This can involve a drop of water which inadvertently fell on the mould; a thumb of the coucher placed on the still wet sheet, a sudden displacement during couching, an uncautious handling during the drying process, improper polishing of the sheet, etc (Barrett 2018, 113-120). In addition, printing with moveable type leaves dent on the paper, which is usually not completely pressed out by the binder. And when rebound, sheets are sometimes washed out, and sometimes pressed again, individually or in quires. This is sometimes done so thoroughly, that nearly every aspect of natural handlaid paper is removed.

Graph 1. **Thickness measured every five mm on a double leaf of an incunabulum showing the wave caused by the «promener» by the vatman**




Note: Thickness (in 1/1000 mm) of fol. [A]5 verso-6 recto, bottom and top, copy Liège BU XV.B.185

## 6. Measuring handlaid paper

With these facts in mind, it should be clear that it is impossible to establish "the" exact thickness of a handlaid sheet of paper. Depending on where one lands on a sheet with a measuring instrument, one will find a different result. The thickness of a single sheet could therefore never be correctly defined by a single value, but it should be rendered by a large enough collection of values, from which a range, an average value, and a median value can be derived mathematically. In order to have a reliable estimate of both mean and standard deviation on the level of a single sheet, limiting the effect of undersampling larger values due to probability concentration about the mean on the standard deviation, a sample of at least 30 points randomly distributed over the entire sheet would be required.

The precision instrument used for this survey, however, does not allow for this method. I used a professional instrument Käfer type FD 50 C with a precision up to 1/1000th of a millimeter.[4] This instrument has a number of limitations. It can only measure up to maximum 50 mm away from the edge of a sheet, which means that only the outer margins are in reach. It cannot measure objects thicker than 12.5 mm. The measuring surface is round and has a diameter of 10 mm, which means that the instrument can only detect the highest point under that surface. As a result, the thinnest spots on the sheet will remain invisible and therefore unknown. On the other hand, the instrument is calibrated, and its maximum deviation is negligible for this kind of research. It is easy to manipulate, and tests with a second, identical instrument proof that the results are very reliable (Schweizer-Martin, Proot & Jacquet 2023 [in press]).

When measuring leaves in early modern books, one has to avoid some obvious areas. Deckle edges, as well as defects in the paper such as tears, holes, and knots will evidently result in ouliers. If possible, one should also avoid the printing area (dent) and stay in the blank margins, but in small bibliographial formats of books (octavo and smaller), this is not always possible.

In 2021, I developed a method to measure the thickness of sheets of early modern folio books (Proot 2021b). In the folio format two pages are printed on each side of a sheet of paper, in total four pages on one sheet recto/verso. The sheets are folded once and assembled to form quires, which are usually bound. After a thorough analysis of different series of measurements on three copies of the same edition, the following conclusions were made.

- As a rule, it is possible to obtain a very good idea of the 'overall' thickness of a sheet in folio books selecting "only" 14 evenly spread measuring points in the margins for a limited number of sheets, e.g., 10 (see Figure 7).
- In most cases, it is even possible to detect the thicker 'short edge' and the thicker 'long edge' of the sheet based on 14 evenly spread measuring points in the margins.
- As a rule, sheets landed randomly on the press, with the watermarks oriented at random (upright, upside down, in the left half, in the right half of the sheet). It is very likely that this was done on purpose to prevent skew book blocks.
- Statistically, seven selected measuring points on one side of a sheet – one leaf in a folio book – also render a very good idea of the thickness of the sheet to the order of magnitude of the difference in thickness between the thinner and the thicker side of the sheet. For the distribution of these points, see Figure 7.
- The thickness of one point measured right in the middle of the short edge (the so-called midpoint, in the outer margin) gives a very good indication of the order of magnitude of the average value of six points distributed evenly over the margins of a leaf (see Figure 7).
- The combined thicknesses of the midpoint in the outer margin measured on ten subsequent leaves is higher than the thickness of that point measured on a stack of ten leaves measured at once. This results from the so-called compression effect, whereby stacked leaves ajust to each other so that mountains and valleys

[4] For the technical specifications, see: https://praezisionstools.de/mwgpt/dicke/skd001/Messuhr_KA20054-c.html#details; see also https://praezisionstools.de/kataloge/mwgpt_dicke.pdf at page 25 (last consulted 8 April 2022).

accomodate like spoons (compare the waves on Graph 1). The difference in thickness observed in the testcase is about 9%.
- Depending on the specific characteristics of the paper, the compression effect can be reversed when a stack of leaves measured at once becomes too voluminous. At a given moment, it becomes rigid and stiff, which results in higher values than one would obtain when leaves are measured individually and subsequently values are added up.
- The thickness of leaves in books which have been rebound, can be reduced by 10% and more compared to books in their original binding.

From this testcase, we retain the following. If we want to compare values across books, we should always use the same method to measure the thickness. Measures should be taken at the same spot, always on the same number of subsequent leaves, and always in the same way: either each leaf individually, or the complete stack of leaves at once. For the survey discussed below, I systematically applied the same measuring method.

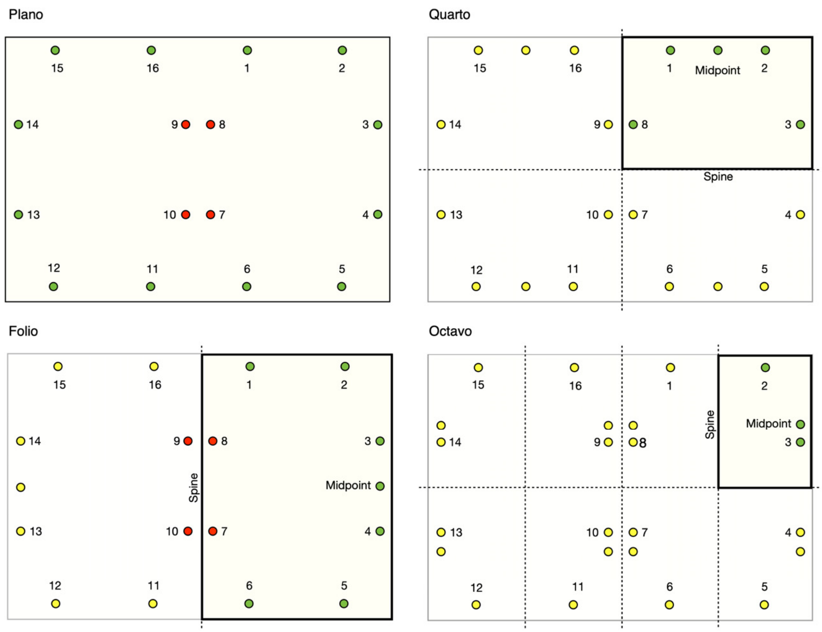
## 7. Comparing thickness in different bibliographic formats

Weaponed with this knowledge, I recently developed a method to compare paper thickness through different bibliographical formats, in casu, folios, quartos and octavos. These three formats are the most important ones for books produced in the Southern Netherlands which were collected by institutional libraries (Proot 2021a, 243-244). For each format, a number of measuring points is selected in such a way that they always have a number of measuring points in common with the other formats. For folios they include two points in the upper and lower margin of the leaf, and three points in the outer margin. For quartos five points are measured, i.e., one in the upper and the lower margin, and three in the outer margin. In the case of octavos, three points are measured: one in the upper margin and two in the outer margin. All three formats directly have both points 2 and 3 in common (Figure 7).

The points in green are directly in reach for measuring. In books, sheets are folded to form gatherings, so when 10 leaves in a folio book are measured at once, point 1 corresponds with point 16, point 2 with point 15 and so on. The points measured indirectly are marked with yellow for each bibliographical format. Only in the folio format, four points in the middle of the sheet are out of reach (point 7, 8, 9, and 10, marked in red). They are located next to the spine.

Between 1 and 9 April 2022 in total 379 books produced in the Southern Netherlands in the holdings of the Royal Library in Brussels were measured this way: 87 folios, 201 quartos and 91 octavos. The temperature in the reading room fluctuated between 19.3°C in the morning to 24.5°C in the afternoon, and along with it the relative humity slowly dropped from 44% in the morning to 28% in the afternoon. The effect of these fluctuations on the paper thickness of handpress books has not yet been studied. Only 15% of the copies consulted was found in its original binding (58), and in many cases those copies, too, underwent at one point or another treatment (e.g., rebacking, new flyleaves). The majority of the copies was rebound in the nineteenth or twentieth century, some probably even more recently. It was not yet possible to consult the files about the restoration work and further to detail the exact nature of the interventions.

Fig. 7. **Measuring points on a full sheet, a folio, quarto, and octavo leaf**




From a previous study, we know that rebinding may have a serious impact on paper thickness (Proot 2021b). Only six incunabula were found in their original binding, each time two per decade between 1471 and 1500. This means that the majority of the values found for this period probably are rather on the low side. In contrast, seven in seventeen copies from the period 1551-1560 probably were never rebound, implying that the numbers for this decade may be rather on the high side compared to the rest of the dataset. Unfortunately, the different subsets are not large enough to perform statistical tests to verify potential correlations.

Tab. 1. **Paper thickness of 10 leaves measured at once at points 2 and 3 (1/1000 mm) (April 2022)**

| Decade | Format | Copies | Thickness at point 2 | Thickness at point 3 |
|---|---|---|---|---|
| *1471-1480* | | *34 (original binding: 2)* | *1733.4* | *1686.1* |
| | Folio | 27 | 1765.9 | 1682.5 |
| | Quarto | 7 | 1608.1 | 1700.0 |
| *1481-1490* | | *63 (original binding: 2)* | *1446.1* | *1453.2* |
| | Folio | 27 | 1506.6 | 1473.2 |
| | Quarto | 33 | 1405.9 | 1448.4 |
| | Octavo | 3 | 1344.3 | 1325.0 |
| *1491-1500* | | *28 (original binding: 2)* | *1319.4* | *1323.5* |
| | Quarto | 19 | 1312.3 | 1315.9 |
| | Octavo | 9 | 1334.4 | 1339.4 |
| *1501-1510* | | *52 (original binding: 10)* | *1254.7* | *1274.1* |
| | Folio | 7 | 1485.3 | 1406.7 |
| | Quarto | 28 | 1279.6 | 1307.6 |
| | Octavo | 17 | 1118.7 | 1164.1 |
| *1511-1520* | | *72 (original binding: 8)* | *1252.3* | *1256.4* |
| | Folio | 12 | 1368.0 | 1275.8 |
| | Quarto | 56 | 1231.8 | 1259.6 |
| | Octavo | 4 | 1192.0 | 1153.5 |
| *1521-1530* | | *50 (original binding: 9)* | *1216.6* | *1240.4* |
| | Folio | 7 | 1380.6 | 1339.3 |
| | Quarto | 34 | 1174.0 | 1214.6 |
| | Octavo | 9 | 1250.1 | 1261.0 |

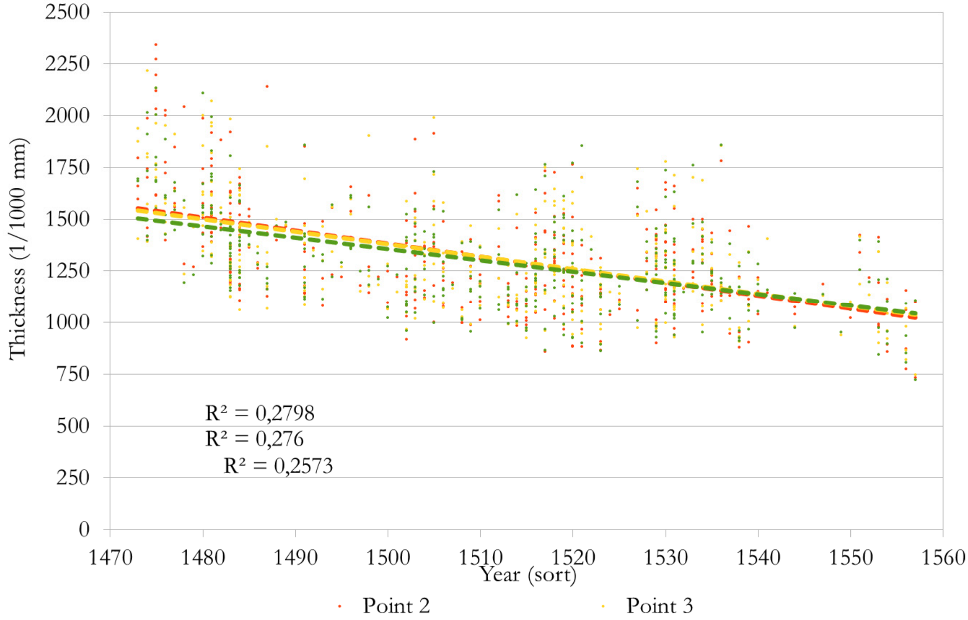
| | | | | |
|---|---|---|---|---|
| *1531-1540* | | *56 (original binding: 16)* | *1219.6* | *1232.2* |
| | Folio | 7 | 1387.3 | 1383.7 |
| | Quarto | 19 | 1243.1 | 1289.2 |
| | Octavo | 30 | 1165.7 | 1160.7 |
| *1541-1550* | | *7 (original binding: 2)* | *1088.0* | *1104.0* |
| | Quarto | 1 | 1143.0 | 1405.0 |
| | Octavo | 6 | 1078.8 | 1053.8 |
| *1551-1560* | | *17 (original binding: 7)* | *1066.7* | *1052.8* |
| | Quarto | 4 | 1229.3 | 1214.0 |
| | Octavo | 13 | 1016.7 | 1003.2 |
| *Total* | | *379 (original binding: 58)* | | |

Graph 2 shows the distribution of the thickness measured on point 2 and 3, and on the midpoint. While the trendlines for point 2 and 3 almost completely overlap, the trendline for the midpoints (in green) starts a little bit lower and ends just a tiny bit higher on the graph. This may have to do with the position of the midpoint, which is different for folios – which is the dominant format in the period 1471-1480 –, quartos – dominant between 1481 and 1530 –, and octavos (compare Figure 7).

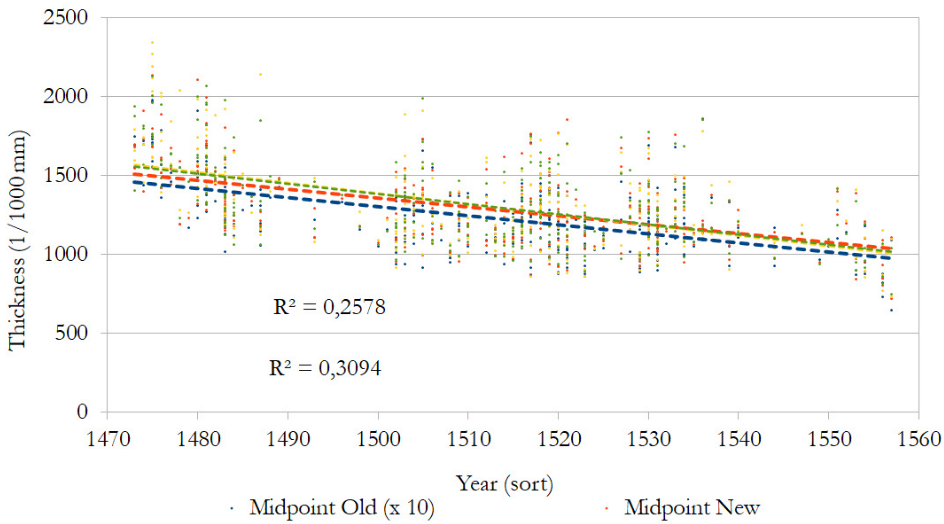
For 312 copies of the above described dataset, we possess additional data collected back in 2017, collected with a different, less precise electronic caliper. In contrast to the Käfer model described above, this caliper did not work with a spring, but had to be closed by hand. Because it is impossible to exercise each time exactly the same pressure, this must have influenced the results. In addition, this caliper measured only up to 1/100 mm.[5] Graph 3 compares the values obtained with the caliper used in 2017, and those from April 2022. The results from 2017 are multiplied by ten, so that both series can be plotted on the same scale (1/1000 mm).

[5] Unfortunately, on 1 November 2017 Polish customs confiscated this instrument when I wanted to board the airplane for Brussels, as they considered it a potential offensive weapon. Therefore I cannot give any more details about it.

Graph 2. **Thickness of points 2 and 3, in addition to that of the midpoints (in 1/1000 mm), taken from 379 copies produced in the Southern Netherlands between 1473 and 1557 (April 2022). Each time 10 leaves were measured at once**




Graph 3. **Thickness of midpoints measured in 2017 (Old) and in 2022 (New), using different calipers.**



For the period 1471-1560, both trendlines for midpoints run parallel, thus confirming the trendlines plotted on Graph 2 for measuring points 2 and 3. The values of the midpoints registred in 2017 are systematically lower than the values measured in April 2022. The difference between both values calculated on the entire dataset of 312 records is 4.3%. This gives a handle to interpret the values in Table 2, especially those from the second half of the sixteenth century, for which extra datacollecting according to a reliable method and with a precision instrument is still wanting.

Tab. 2. **Average paper thickness of 10 leaves on midpoint (1/100 mm) (2017)**

| **Decade** | **Format** | **Copies** | **Thickness on midpoint (1/100 mm)** |
|---|---|---|---|
| *1471-1480* | | *69* | *157.6* |
| | Folio | 60 | 158.4 |
| | Quarto | 9 | 152.4 |
| *1481-1490* | | *128* | *139.6* |
| | Folio | 52 | 148.0 |
| | Quarto | 67 | 135.4 |
| | Octavo | 9 | 122.0 |
| *1491-1500* | | *32* | *124.5* |
| | Folio | 3 | 148.3 |
| | Quarto | 20 | 126.0 |
| | Octavo | 9 | 113.0 |
| *1501-1510* | | *78* | *121.2* |
| | Folio | 9 | 128.1 |
| | Quarto | 44 | 124.3 |
| | Octavo | 25 | 113.2 |

| | | | |
|---|---|---|---|
| *1511-1520* | | *95* | *120.0* |
| | Folio | 19 | 123.1 |
| | Quarto | 69 | 120.1 |
| | Octavo | 7 | 111.0 |
| *1521-1530* | | *69* | *113.6* |
| | Folio | 10 | 122.5 |
| | Quarto | 38 | 110.6 |
| | Octavo | 21 | 114.7 |
| *1531-1540* | | *83* | *115.2* |
| | Folio | 9 | 140.1 |
| | Quarto | 18 | 122.2 |
| | Octavo | 56 | 109.0 |
| *1541-1550* | | *31* | *101.2* |
| | Octavo | 31 | 101.2 |
| *1551-1560* | | *95* | *104.5* |
| | Folio | 6 | 123.7 |
| | Quarto | 23 | 104.4 |
| | Octavo | 66 | 102.8 |
| *1561-1570* | | *29* | *106.3* |
| | Folio | 5 | 110.2 |
| | Quarto | 1 | 117.0 |
| | Octavo | 23 | 105.0 |

| | | | |
|---|---|---|---|
| *1571-1580* | | *26* | *117.2* |
| | Folio | 8 | 116.9 |
| | Quarto | 6 | 139.3 |
| | Octavo | 12 | 106.3 |
| *1581-1590* | | *16* | *116.1* |
| | Folio | 4 | 111.8 |
| | Quarto | 4 | 131.3 |
| | Octavo | 8 | 110.8 |
| *1591-1600* | | *21* | *118.7* |
| | Folio | 2 | 121.5 |
| | Quarto | 4 | 117.3 |
| | Octavo | 15 | 118.7 |
| *Total* | | *672* | |

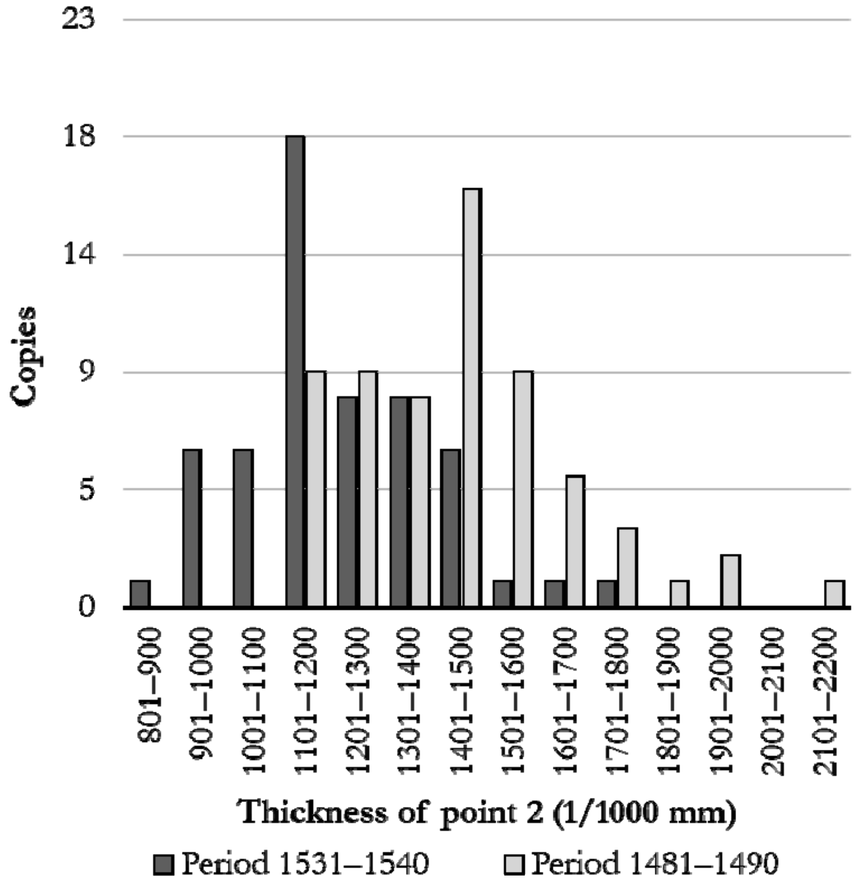
Although the subsets for the period after 1560 are not very substantial, the average thickness goes up again, from about 1.06 mm for 10 leaves in 1561-1570 to about 1.18 mm in the last decade of the sixteenth century.

Another observation one may make, is that in a given decade the paper of folios is, on average, often thicker than that in quartos, which in turn is often thicker than that of octavos. In the period 1481-1490, the average thickness of point 2 for folios is about 1.50 mm for 10 leaves against 1.41 mm for quartos (see Table 1). In the period 1501-1510, the average thickness of point 2 for quartos is about 1.28 mm for 10 leaves against 1.12 mm for octavos, and one decade later, the numbers are about 1.24 mm for quartos against 1.17 mm for octavos. This seems to be confirmed by most values in Table 2, but more data are required to confirm this trend statistically.

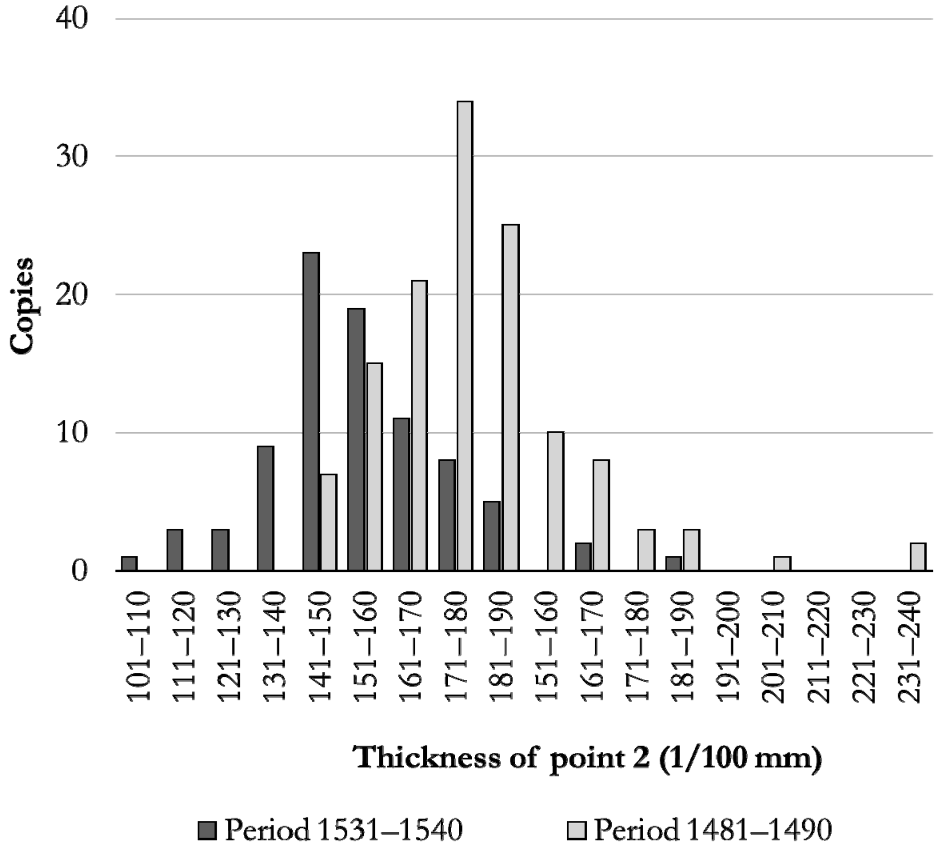
The coefficients of determination ($R^2$) of the trendlines on both scatterplots Graph 2 and 3 have values between about 0.2578 (value for midpoints measured in April 2022) and 0.3094 (midpoints recorded in 2017), which means that time (x-axis) explains only part (about 25 to 30%) of the observed variance (Blondé et al. 2012, 138-139). The $R^2$ values reported are relatively low but statistically significant. They can be said to be weak. However, the scatterplot does not provide indications that would motivate a higher order or complex modelling. In itself, the importance is the identification of a trend. This is a first step and further investigation is needed in order to identify influencing factors through more sophisticated sampling and additional information in combination with advanced modelling. Influencing factors may be, amongst other, bibliographical formats and different sheet sizes.

The distribution of the individual values on Graphs 2 and 3 indicates that there is a fairly wide choice in paper thickness. Graphs 4 and 5 give an overview of this distribution for two decades, for which subsets in both Table 1 and 2 hold enough datapoints to draw a usefull picture. Graph 4 is based on the actual thickness of 10 leaves taken on point 2 in April 2022, for the period 1481-1490 and fifty years later, in 1531-1540. Graph 5 shows data from the same decades, but they are taken from measurements of midpoints recorded in 2017.

Graph 4. **Distribution of thickness taken on point 2 (1/1000 mm) of copies published in the period 1481-1490 and 1531-1540 (April 2022)**



Graph 5. **Distribution of thickness taken on the midpoint (1/100 mm) of copies published in the period 1481-1490 and 1531-1540 (2017)**




Both Graphs 4 and 5 show that in both decades printers had access to paper of different thicknesses. This seems to be confirmed by Figures 5 and 6, taken from the survey by Barrett et al. in 2016. In the period 1481-1490, the paper thickness varies between 1.10 mm (for 10 leaves) and 2.20 mm (Graph 4). Fifty years later, the thickness for 10 leaves ranges between 0.80 mm and 1.80 mm. In the first period, there is a clear preference for rather thick paper: 52% of the copies is printed on paper with a thickness of 1.30 to 1.60 mm for 10 leaves (data from April 2022). Half a century later, 57% of the paper has a thickness of 1.00 to 1.30 mm for the same amount of leaves (April 2022). For the first period there has no use of extremely thin paper been recorded, and fifty years later, extremely thick paper seems to have fallen out of use. What both Graphs 4 and 5 proof, is that, at all times, paper of a wide variety of weights was available, and that printers always had – to a certain degree – options.

## 8. Discussion

The notion that printers always had a choice between thinner or thicker paper, is essential, because it makes clear that what we can observe in the books and see on the graphs is not the result of mere chance. Well on the contrary, the selection of this or that paper stock was a deliberate decision, and thus meaningful.

The selection of thick, and in some cases, extra thick paper in the beginning of the printing press, suggests that printers in the Southern Netherlands opted for a canvas which look and feel was quite close to that of parchment. The paper thickness corresponded fairly well with that of parchment (Proot 2017, 21), and as Timothy D. Barrett has pointed out, the heavily sizing with gelatine in the beginning of the handpress era also added to the resemblance between the two materials (Barrett 2013, 120). From a cultural point of view, this makes a lot of sense. Certainly in the beginning of the handpress period, printers and publishers mainly produced large and impressive books for audiences which were used to a certain degree of quality and luxury. Hence the dominance of folios during the first years of printing, also in the Southern Netherlands. Printers and publishers for this public would not want to make their books look cheap. The look and feel of all aspects had to correspond as much as possible with prevailing standards. It has often been pointed out that the first generations of printers wanted to 'imitate' manuscript books. What actually happened, is that the only thing they changed was the way the main text was put on the canvas. This was no longer executed by clecks and copyists, but mechanically with type and presses. All other aspects of the layout remained the same; like manuscrips printed books remained only half-products until rubricators and illuminators had completed them.

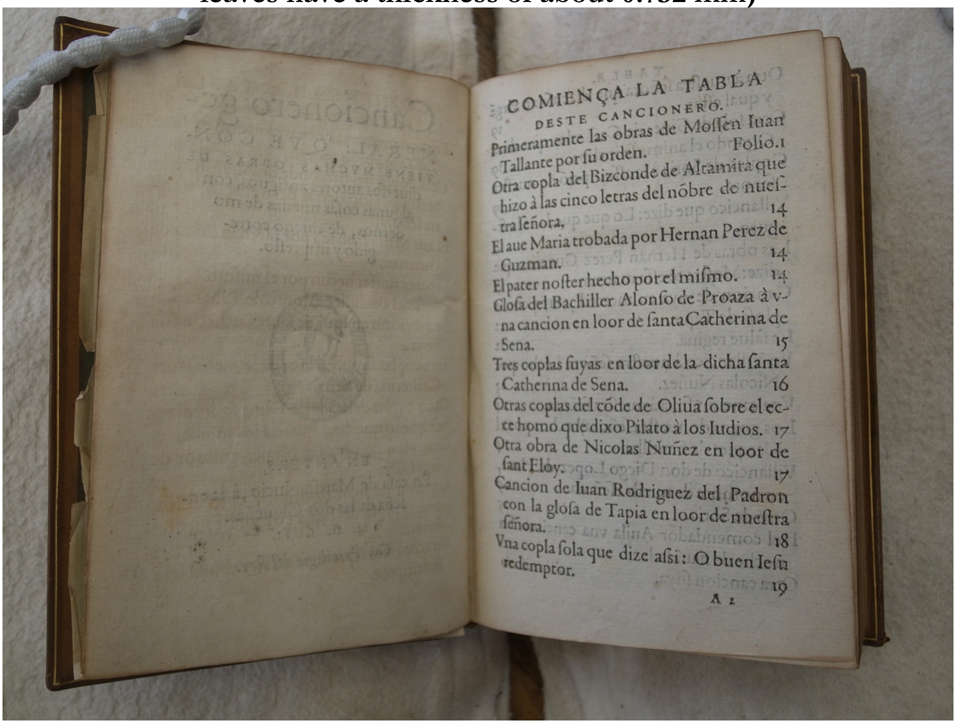
When the public had more or less accustomed to the new books, slowly but surely one aspect after the other one underwent change in order to make books cheaper and better. I have described different aspects of this process in a number of publications (Proot 2017; 2021a; 2022). The most visible transitions include the growing importance of smaller bibliographical formats (first quarto, then octavo, and smaller formats), the increase of type areas and the reduction of white margins, the development of smaller type, and the substitution of navigation aids in colour by printed paragraph marks, printed larger and ornamental initials, and the functional use of white to add structure (indentation, white lines). Amongst these phenomena, the overall reduction of the paper thickness between 1473 and the middle of the sixteenth century is probably one of the most important changes. Depending on the criteria, the average thickness of the paper used to print books in the Southern Netherlands dropped 34 to 38.5 per cent in 80 years. Given the fact the major part of the early books in this survey have been at least once rebound, this number is probably an underestimation.

Paul Schweitzer-Martin has observed the same trend for Speyer in the period 1471-1500. Based on a survey of 200 copies, he also found that printers used at all times paper of different thicknesses, and that the average thickness diminished from about 2.1 mm for 10 leaves in 1571 to about 1.6 mm in 1500 (Schweitzer-Martin 2022, 170, Abb. 47).

The reduction of paper thickness in printed books by, let's say one third in about 75 years, has at least four important results. All four effects are economic. First of all, more sheets of paper could be produced with the same amount of raw materials. Compared to 1473, about one third more in 1550. Second, if the weight of books is lowered, transportation costs decrease as well. Third, printers, publishers and booksellers need less space to warehouse copies waiting for sale. Fourth, purchasers need less space to shelve books.

In spite of the economic benefits of the reduction of the paper thickness, this process had reached its limits around the middle of the sixteenth century. Very thin paper has also disadvantages. First of all, it is much harder to manipulate and to print on it with a relief press without piercing it. Second, thinner paper is more translucent and may show the printing on the verso, which disturbs reading (Figure 8). In addition, it is probably more difficult to manifacture.

Fig. 8. **Text of the verso showing.
Fernando del Castillo, *Concionero genera*l. Anvers: Martin Nucio, 1557, octavo (copy Royal Library Brussels, LP 5.523 A, fols. A1v-A2r. Ten leaves have a thickness of about 0.732 mm)**




## 9. Conclusion

The changes in paper thickness during the first decades of printing had lasting effects both on book design and economy. The reduction of paper thickness allowed for savings on many levels, and probably helped meeting a dramatically increasing demand. The success of this process lays in the fact that it went by slow enough to remain basically unnoticed – not in the last place by most scholars.

In spite of its relevance for our understanding of the development of the book market, the research of paper thickness in the handpress era is scarcely out of the egg. The desiderata in this field are legion. On a methodological level, we still need better to understand the impact on paper thickness of binding and rebinding. Neither do we know how differences in storage climate (temperature, relative humidity) work out on paper thickness. Also the compression effect of paper requires more study. To what extent, for instance, does it depend on paper thickness and on different levels of sizing?

More data are required in order to identify correlations other than time. It is likely that the other two dimensions of the sheet (height and width) can be linked with thickness. There are strong indications that printers opted for thinner papers stocks for smaller bibliographical formats. We also have the impression that they opted even more consciously for paper with specific characteristics in the case of specific projects, especially in the second half of the sixteenth century and later. It is a fact that printers and publishers such as Christophe Plantin (c. 1520-1589) and his successors systematically exploited the possibilities of paper for product differentiation.

To conclude, it is obvious that this subject requires an international approach.

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