THE URBINO CLAVICHORD REVISITED

BY PIERRE VERBEEK[1]

This contribution stems from a long-standing project to build a replica of the fifteenth-century clavichord represented on the walls of the *studiolo* of the Ducal Palace at Urbino, in the Marche region of Italy [Fig. 1]. Early in 2011, Bernard Brauchli introduced the author to Dr.ssa Vittoria Garibaldi, the Sopraintendente per i Beni Storici delle Marche, who granted permission to study the clavichord intarsia closely and to take all necessary measurements and photographs.

Fig. 1. Workshop of Baccio Pontelli: Clavichord (c. 1479), Palazzo Ducale, Urbino. Normal view

The purpose of this paper is to share the outcome of this closer look. The paper provides new data and suggests a number of revisions to measurements which have been published previously.[2]

The construction of the Ducal Palace at Urbino, which began *c.* 1450 and ended *c.* 1582, was the result of a wonderful conjunction between the intelligence and the money of

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[2] Edwin M. Ripin, 'The Early Clavichord', *Musical Quarterly*, 53/4 (1967), pp. 518–38; Angelo Mondino, *Il Clavicordo – Interpretazione e Ricostruzione di Antici Strumenti a Tastiera*, Coll. Musica Ragionata, 5 (Lucca: Libreria Musicale Italiana Editrice, 1993); Denzil Wraight, *The Stringing of Italian Keyboard Instruments c. 1500– c. 1650*, Ph.D. dissertation, Queen's University of Belfast, 1997.

Duke Federico (III) da Montefeltro (1422–1482) and the co-operation of most prominent architects, painters, sculptors, cabinet-makers, musicians of the time. The *studiolo* is the heart of the palace. For the Duke, his *studiolo* is not only a private room devoted to private contemplation: it is also a room of representation. Here, Duke Federico da Montefeltro builds an image of himself and shows it to others. This room is a seminal site of the first Italian Renaissance. Apart from Gubbio *studiolo*, now in New York, it is the only room of that sort which has been preserved, with most of its paintings and all of its marquetry.

The Urbino *studiolo* is a small irregular room, nearly square, about 12 square metres, in a half-light, where one is struck by the abundance of decoration and by the darkness of the place, lightened only by one rather small window. The paintings of *Famous Men* on the upper part of the *studiolo* walls are by Joos van Ghent (Giusto da Guanto, Juste de Gand): twenty-eight portraits of illustrious men (Albertus Magnus, Dante, Petrarch, Moses, Solomon, Plato, Aristotle, Ptolemy, Cicero, Homer, Virgil, Euclid, and others), painted in 1473–1475. The intarsia below the paintings was made by the best cabinet-maker of the time, Baccio Pontelli (*c.* 1450–1492). He allegedly used designs of Sandro Botticelli or other prominent artists around Duke Federico.

At first glance, the objects depicted on the intarsia are in disorder: the whole room seems to be a collection of disparate pieces of art, gathered together at random, seemingly just in order to show how the Duke lived in private. But it is now known that the *studiolo* was not made at random: it has a very specific iconographic programme.[3] The clavichord on the north wall of the *studiolo* plays a role in that iconographic programme. A study of that role is well beyond the scope of the present contribution, which is confined to technical and organological issues. Indeed, the intarsia also provides detailed evidence on the objects represented. There are scholars from all over the world who come to Urbino just for that: to examine those parts of the room devoted to their area of expertise: astronomical instruments, books, cabinet-making, semiology, and organology. Among numerous other objects, the clavichord on the north wall of the *studiolo* is represented with amazing accuracy. The precision is such that it is possible to reverse the perspective and to obtain an accurate technical drawing of the 'real' clavichord, including many details.

Main findings

The main findings of the present analysis for the 'real' clavichord are the following. The outer dimensions of the 'real' clavichord are 1005 mm × 216 mm × 82 mm excluding the keyboard (± 1 mm). Its case-wall thickness is twelve millimetres (± 0.5 mm). As for the keyboard dimensions, the octave span is 177.5 mm, the width of the naturals, all equal, is 25.3 mm, the width of the sharps is 14.0 mm, the projecting length of the naturals is 81.5 mm, the apparent key dip is 4–6 mm. From the position of the bridge and tangents, one can deduce that the string lengths are reasonably Pythagorean except in the lower octave. The instrument is double-strung, with seventeen choirs (thirty-four strings), but with thirty-six tuning pins. All tangents are in the form of staples. Two tangents are missing. The fretting scheme is 3–4–3–4... consistently after the bass octave. The temperament is Pythagorean tuning, with the wolf fifth on B–F#. The pitch might have been a^1 = 440 Hz or higher.

This paper provides details on all those points: these dimensions and those conclusions flow directly from the evidence of the intarsia. Interpretation is kept to a minimum.

[3] Daniel Arasse, 'Frédéric dans son cabinet: le Studiolo d'Urbino, Le sujet dans le tableau, essai d'iconographie analytique', *Champs arts*, Paris, 1997, 2006, pp. 27–55.

Technical drawings of the clavichord in the intarsia

Everything in the *studiolo* looks three-dimensional but everything is flat surface. The *trompe-l'œil* is of such quality that anyone entering the room thinks that the objects, drawers, shelves, doors, are real. In those circumstances, one must admit that it is very easy to create confusion between the representation of the objects and the objects themselves. The excellence of the *trompe-l'œil* is such that mistakes are very easily made when measuring dimensions. A specific vocabulary is required to avoid confusion between measurements on the intarsia and interpretation for the 'real' instrument. It is mandatory to take measurements on the flat surface of the intarsia and to avoid 'contamination' of those basic measurements by any preconception about the 3D real instrument. For communication purposes, the following vocabulary convention is proposed: we shall use *mm-I* for the 2D representation and *mm-R* for the 3D interpretation. This convention will prove useful in the course of the following discussion.

In order to solve the reverse perspective problem for the clavichord, one needs to have a precise idea of the framework in which Baccio Pontelli had to design the intarsia. The *studiolo* is approximately four metres wide and three and a half metres long. The north wall faces the visitor when entering through the south door. He or she takes a few steps and then stops, after one metre and a half, at exactly 2.7 metres in front of the north wall. Now he or she sees the marquetry on the wall as if it were three-dimensional. This is what Baccio Pontelli wanted to achieve for the north wall. And similarly, *mutatis mutandis*, for the other walls, which have not been examined with the same attention.

The clavichord lies on a shelf in the right-hand corner, just under the portrait of Federico. The apparent height of the shelf is approximately sixty-seven centimetres. The apparent length of the clavichord is approximately one metre. The closer one comes to the instrument, the less it looks like a real instrument. It becomes distorted. Anamorphic effects begin to modify the visual perception. The distortion is very significant, for example, when one walks to the right-hand corner of the room and looks straight ahead at the clavichord in the intarsia. This is the so-called 'normal view'.

Normal view: the main dimensions of the clavichord in the intarsia

Fig. 1 provides a photograph close to the 'normal view' of the clavichord. Remember that this is only a flat surface. A large number of measurements have been made on that flat surface.[4] Our conventional measurement unit for flat surfaces is the mm-I, as defined above. Fig. 2 gives, for reference and further study, a drawing with the main external and internal dimensions, in mm-I, of the representation of the clavichord. The overall length is 1005 mm-I, the overall width 115 mm-I. The apparent case walls of the clavichord are rather thick, twelve millimetres. Note that such measurements are affected by some inaccuracies or 'tolerances'. In our case, the measurement tolerances vary according to the tool used. For long dimensions, very accurate stainless steel flat rules were used; for short dimensions, a good-quality vernier caliper. The tolerance for the longer dimensions can be estimated at around one millimetre. For shorter dimensions, the tolerance is estimated to be approximately one-half millimetre.

[4] Those photographs and drawings and many others, including very interesting details, are available in high definition, on simple request to the author.

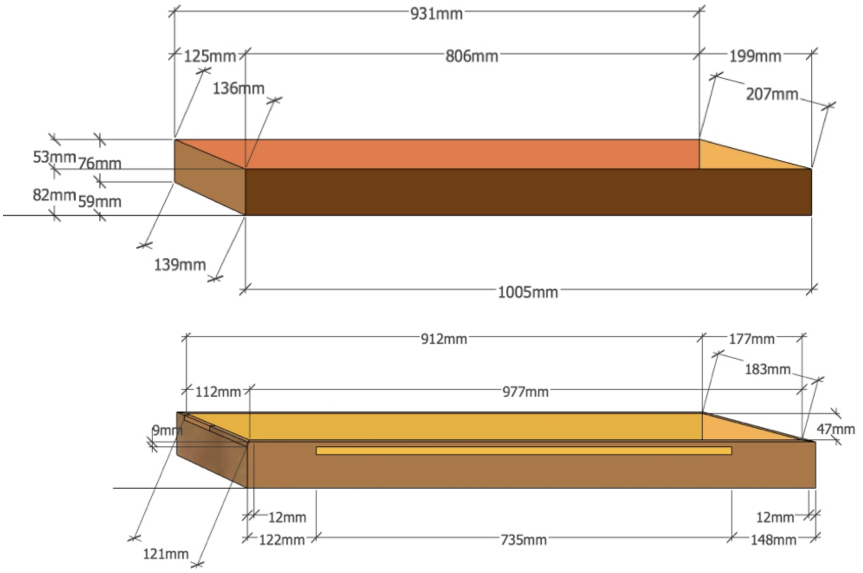

Fig. 2. Main external (top) and internal (bottom) dimensions measured on the clavichord representation, expressed in mm-I

After having determined the main outer and inner dimensions, all details can be measured as well, with similar measurement tolerances. Figs. 3 and 4 show the apparent dimensions of the bridge, the apparent height of the soundboard, the apparent size of the wrestplank, and the main keyboard dimensions. It must be stressed that there is no need whatsoever to postulate anything about the exact position of the bridge or any other item, contrary to what was assumed by some earlier scholars.

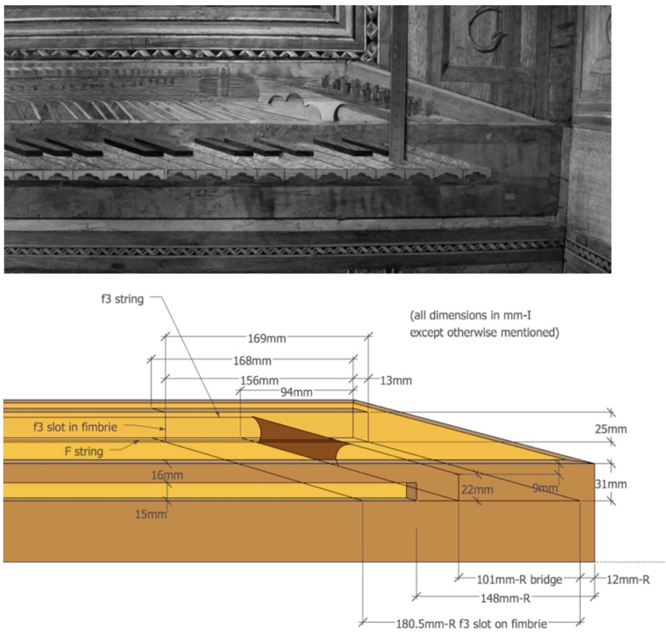

Fig. 3. Position and main dimensions of bridge, soundboard and rack measured on the clavichord representation, expressed in mm-I

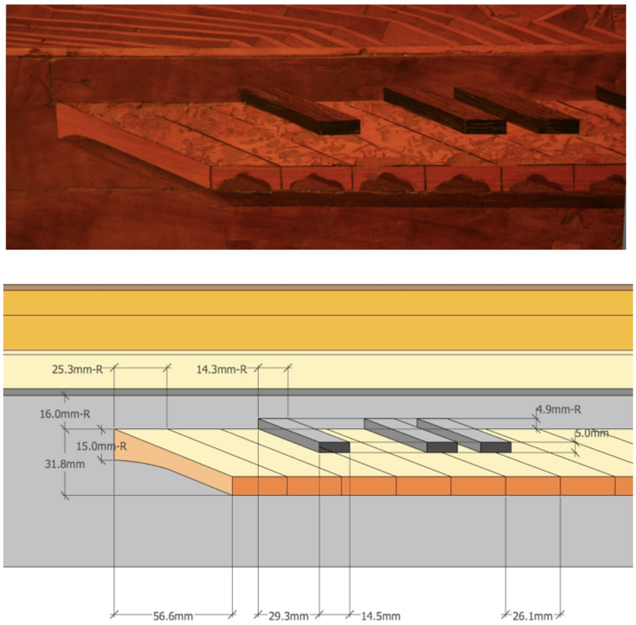

Fig. 4. Main dimensions of keys measured on the clavichord representation, expressed in mm-I (except where stated otherwise)

The keyboard extends from F to f^3. All naturals have the same width, as do all sharps. The sharps are equally spaced. This equality over the whole compass complies perfectly with the rules of perspective as they were developed during the fifteenth century. The natural touchplates are very thin. They look like a thin layer of tortoiseshell. Decorative Gothic arcades cover the ends of the keylevers. Their design is reminiscent of the shape of the bridge. The sharps look very flat, their apparent height above the naturals being approximately five millimetres only. The apparent space between two adjacent sharps appears so narrow that it seems impossible for a player to insert a finger between them.

Hitchpin cover block

Fig. 5 shows a very peculiar feature in the intarsia: there is apparently a wooden block at the extreme left of the instrument. It seems to be rectangular in shape on the ‘real’ clavichord. The drawing in Fig. 5 shows all measurements in mm-I. It seems to make sense to imagine that some (or all) of the hitchpins would have been driven directly into the left-hand case wall. They could then have been protected and hidden by this wooden block. The listing cloth would then have been placed just at the right of the left-hand side of the case, at a place invisible on the intarsia.

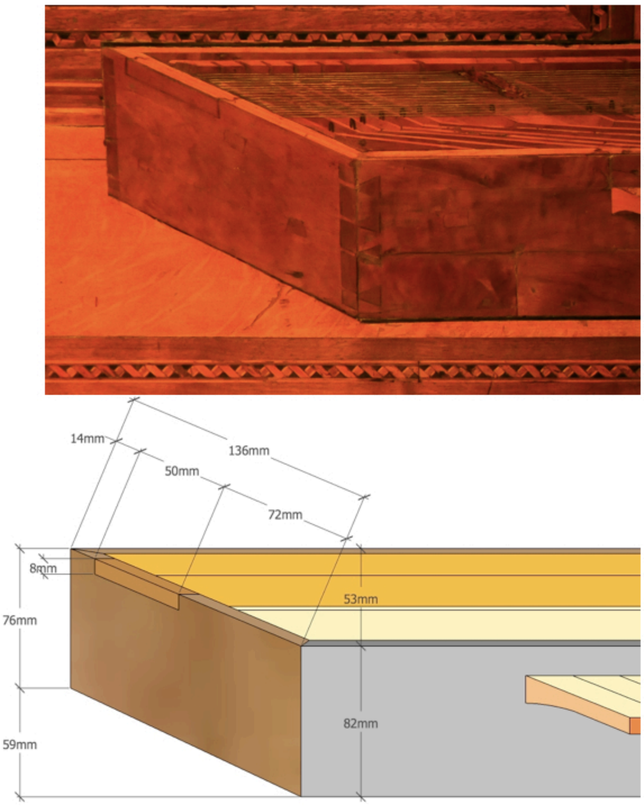

Fig. 5. Hitchpin cover block on the left-hand case wall. Measurements made on the clavichord representation, expressed in mm-I

Slot positions on the rack

The measurements made on the representation of the rack are obviously most important if one wishes to analyse the intonation of the 'real' clavichord. There are many ways to measure the slot positions. For practical reasons and in order to obtain the best accuracy for the ultimate 'real' string lengths, we started from the apparent right-hand internal corner of the clavichord representation. Then for each slot we measured the distance between this corner and the apparent right-hand edge of the slot. Horizontally, the measurements were made along the apparent back f^3 string, which draws a very clear straight line. The apparent position of the bridge was measured in the same way. As Fig. 6 shows, the apparent coordinate of the bridge was determined to be 81 mm-I from the apparent right-end corner. The apparent coordinate of the first slot, for f^3, was 156 mm-I, of the second slot, 161 mm-I, etc. Table 1 (see below) gives all the measurements made for the apparent coordinates of the slots, without any calculation whatsoever. These are data in a raw state, for further study. The measurement tolerances are +/– 1 millimetre.

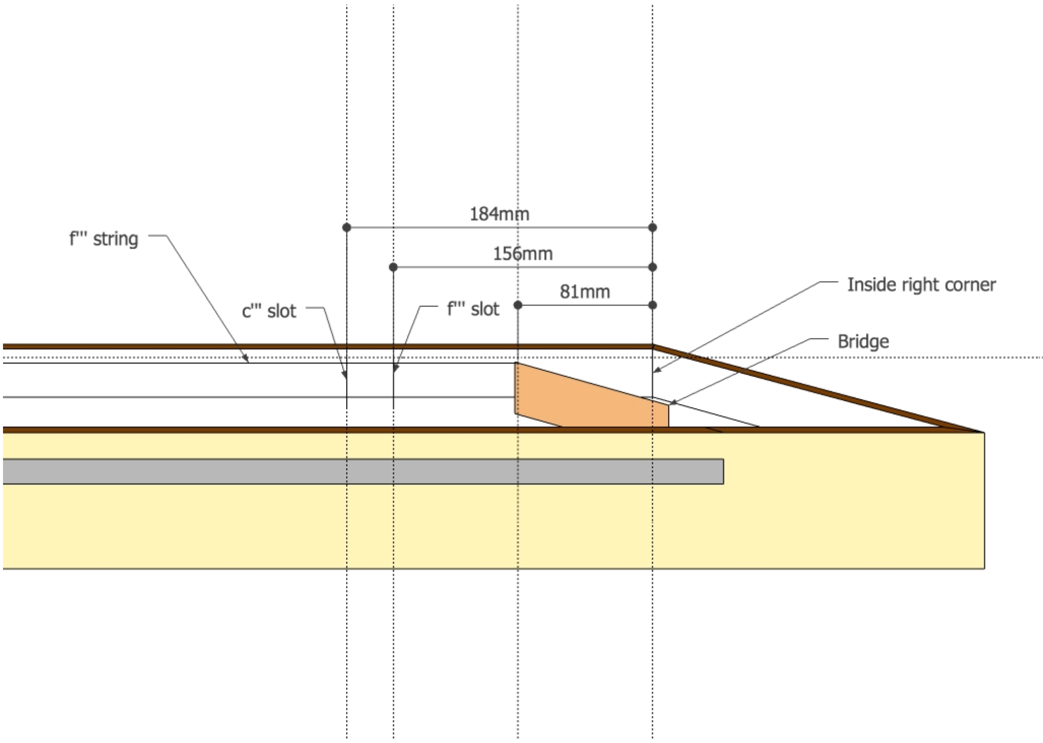

Fig. 6. Method used for measuring slot positions on the rack of the clavichord representation. Measurements are expressed in mm-I

Tolerances: +/– 1 millimetre
Right-hand internal corner to bridge: 81 mm-I

Note	**Position mm-I**	**Note**	**Position mm-I**	**Note**	**Position mm-I**	**Note**	**Position mm-I**
f^3	156	f^2	240	f^1	396	f	640
e^3	161	e^2	249	e^1	407	e	670
$e\flat^3$	167	$e\flat^2$	259	$e\flat^1$	430	e♭	710
d^3	173	d^2	270	d^1	450	d	723
$c\#^3$	177	$c\#^2$	284	$c\#^1$	460	c#	768
c^3	184	c^2	294	c^1	481	c	805
b^2	190	b^1	307	b	500	B	817
$b\flat^2$	199	$b\flat^1$	321	b♭	531	B♭	830
a^2	204	a^1	334	a	541	A	843
$a\flat^2$	213	$a\flat^1$	345	a♭	573	G	853
g^2	222	g^1	359	g	599	F	863
$f\#^2$	232	$f\#^1$	380	f#	609		

Table 1. Rack-slot positions, as measured from right-hand internal corner

Perspective of Federico's *studiolo*

Let us now turn to the 'real' clavichord. Among others, the names of Filippo Brunelleschi (1377–1446) and Leon Battista Alberti (1401–1472) are closely associated with the invention of central perspective. Filippo Brunelleschi was an experimenter of genius. Leon Battista Alberti was more a mathematician. Both of them described essentially the same process. This process, called central perspective, had a profound influence on the 2D representation of 3D realities, from the middle of the Quattrocento until today. The mathematician Alberti will be our guide for understanding and then reversing the perspective of the clavichord in Federico's *studiolo*.

We shall follow closely the geometrical considerations of Leon Battista Alberti in his well-known treatise *Della Pittura* (*On Painting*), 1435–1436, published almost simultaneously in Italian and in Latin. This book has no illustrations. The drawing in Fig. 7 restates Alberti's perspective construction in a modern way. The terms on this drawing are his. The basic idea is expressed by Alberti as follows: 'Know that a painted thing can never appear truthful where there is not a definite distance for seeing it'.[5] The invention of the 'distance', as noted on this drawing, proved of extreme importance for the art of painting at least until the nineteenth century.

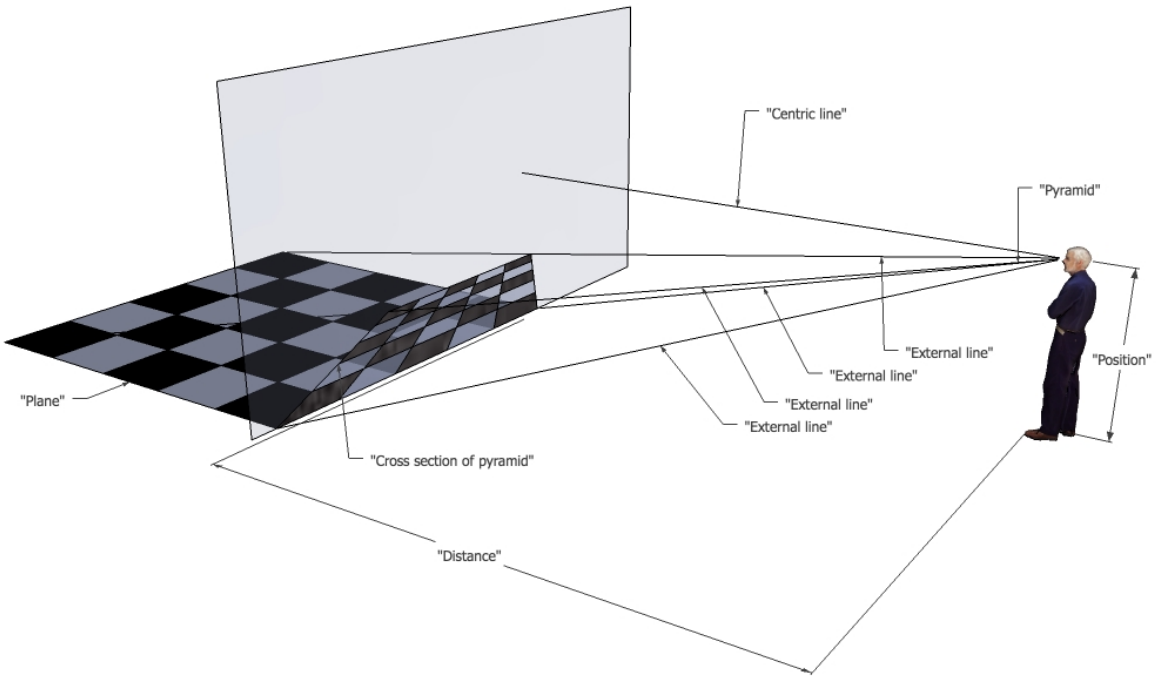

Fig. 7. Principle of Alberti's perspective construction as described in *Della pittura* (1435–1436)

Alberti's theory is based on the consideration of how rays of light, passing from the object to the viewer's eye, cross the picture plane. The rays of light form what Alberti calls the 'pyramid'. For any object, the cross-section of the pyramid by the picture plane determines the 2D representation of the object for the viewer, at the viewing distance. The most external rays of the pyramid, for a given object, are called the 'external lines'. There is one line which is specific: the centric line, which strikes the picture plane at a level equal to

[5] Leon Battista Alberti, *Della pittura*, translated by John R. Spencer, *On Painting* (New Haven and London: Yale University Press, rev. ed. 1966), p. 57.

the height of the viewer. Note that Alberti does not use the words ‘vanishing point’, as we do today. Infinity existed only for heavenly realities, not on the earth.

Construction of central perspective with distance point

The procedure to construct a box in central perspective with the distance point is as follows [see Fig. 8]. Firstly, one draws the centric point, the baseline and the front face of the box, to scale. The height line is then drawn at the height of the viewer (nowadays, this line is called the ‘horizon line’). Secondly, one determines the distance from the viewer to the picture panel; in this case the picture panel is located at the front face of the box. One then marks the distance point on the height line, spaced from the centric point by that distance. Third step: at the left of the front face of the box, one draws horizontally, along the baseline, a line segment whose length is equal to the ‘real’ box width in 3D; one then joins the far end of that line segment to the distance point. The crossing of those two lines determines the apparent width of the box in 2D. The remainder of the construction is straightforward. From the point just determined, one draws all the construction lines necessary to represent the 3D box on the flat surface. This construction is very accurate.

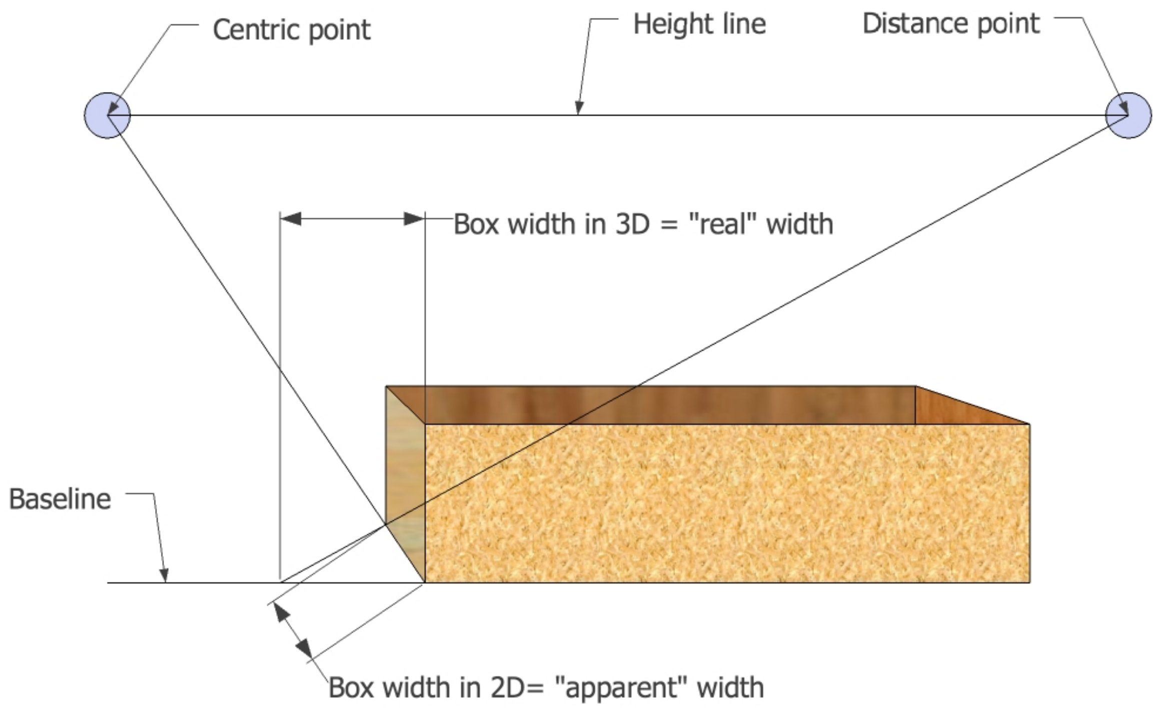

Fig. 8. Practical construction of a box in central perspective with the centric and the distance points

Reversal of the central perspective of the north wall of Federico's *studiolo*

The method summarized above is the one which was used by Baccio Pontelli and his fellow craftsmen for the marquetry of the *studiolo*. Fig. 9 shows the approximate positions of the centric point and of the distance point on the north wall of the room.

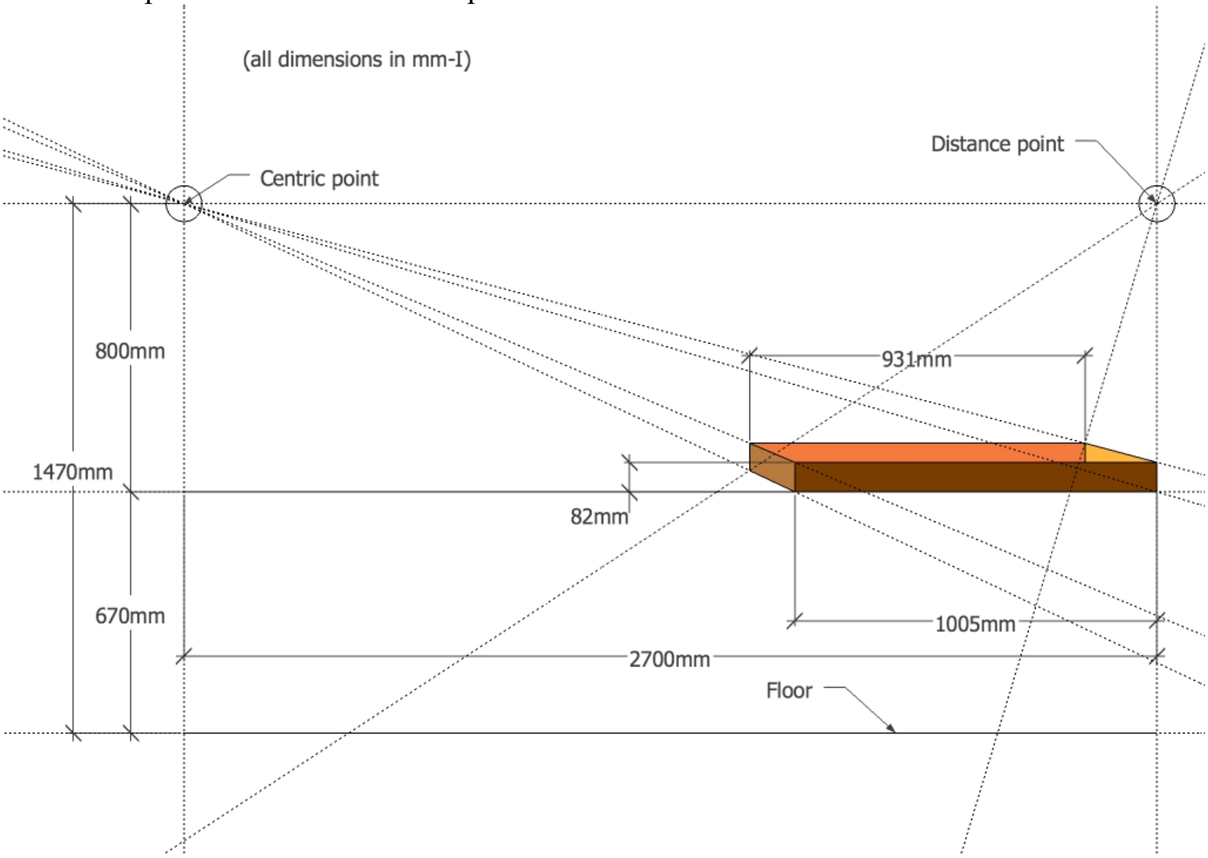

Fig. 9. Proposed reconstructed central perspective of the north wall of Federico's *studiolo*. Measurements are expressed in mm-I

To determine the centric point is simple: in Alberti's words, one must merely continue the 'external lines' of a few apparent pyramids until they cross. The determination of the distance point is much more difficult, since we have no direct information about the real width of the objects represented. Incidentally, that is exactly what we are looking for, such as the width of the 'real' clavichord. There are a number of hints for solving this problem:

1. First, note that, for practical reasons, the distance point must be *inside* the room and not somewhere *inside* the walls, in order to build the objects using stretched strings and rulers.

2. And, second, the distance point for the north wall must apply for *all* the objects that must appear horizontal when one looks at that wall. In other words, there must be a strong internal coherence for all such objects, such as the clavichord, the recorders, the lute, the doors of the cabinets, the shelves, and so on.

Applying those criteria and using measurements and photographs of the north wall, we concluded that the distance point is in the north-east corner, just to the right of Federico's portrait and at the height of the centric point, approximately 1.47 metres above the floor. Accurate checks at Urbino showed that those basic assumptions were right. The rest follows immediately. Knowing the centric and the distance points, it is possible to determine the complete dimensions of all the objects depicted, including the clavichord. Fig. 10 shows one of the constructions for determining the width of the 'real' clavichord: it turns out to be 216 mm-R. Other constructions yield the same result: internal coherence is ensured. Let us stress once more that no assumption need be made to reconstruct this central perspective. There is no need to invoke complicated proportional triangles or conflicting parallel perspective or any complication of that type. It is a simple and rigorous application of Alberti's perspective.

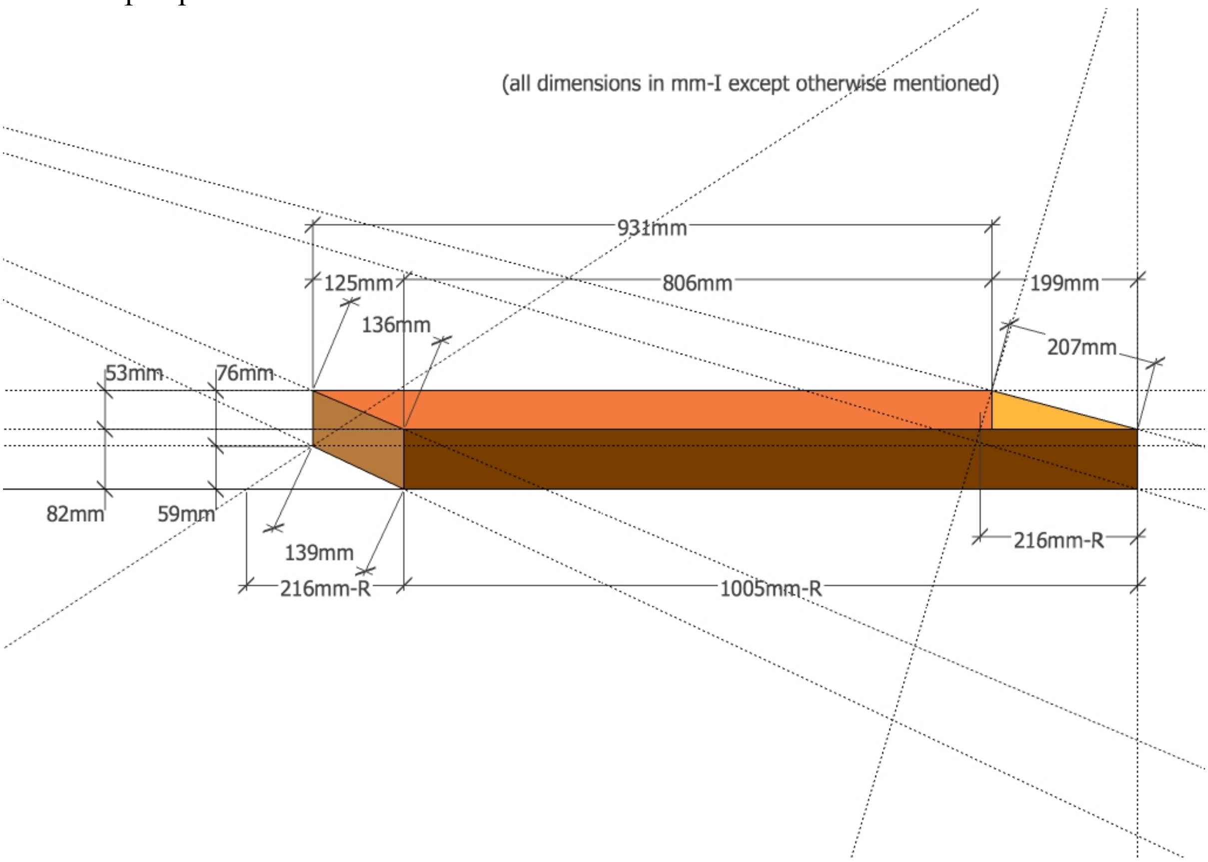

Fig. 10. Proposed reconstruction of the 'real' clavichord width. Measurements are expressed in mm-I unless otherwise mentioned

An *indirect* proof is provided by considering the dimensions of the shelf to the left of the clavichord. In the middle of the north wall, there is a shelf which is shown lifted up. We have thus both the 'real' width of the shelf (302 mm-R, tolerances +/– 5 mm) and the 'apparent' width for the shelf panel just adjacent (166 mm-I, tolerances +/– 5 mm). Accurate measurements of that sort show that the distance point and the centric point assumed here are correct.

A *direct* proof is provided by the observation that there is a wooden patch on the intarsia at the distance point. Indeed, when looking at the place where the distance point is supposed to be, one finds a very small piece of wood inserted into the intarsia. Fig. 11 shows the location of that piece of wood and a close-up of it. It is believed that this wooden patch had the function of covering and concealing the hole made by a nail which was used for drawing the construction lines of the intarsia. In order to create the intarsia, the craftsmen needed a distance point and a centric point. From those points, straight construction lines can be drawn very accurately and the objects can be represented precisely. The Urbino intarsia shows other wooden patches having a similar purpose, as aids for drawing the open doors of cabinets, shelves, armour, books, astronomical instruments, and others. In practical terms, the creation of the intarsia requires that the distance point and the centric point be inside the room and not somewhere in the walls. From those points, straight construction lines can be drawn, strings can be tightened very accurately and the objects can be represented precisely, without any distortion. Theoretically, using hundreds of proportions and trapeziums would achieve the same result, but at the cost of a significant loss of accuracy and a huge amount of calculation work. The Quattrocento engineers used geometry, not algebra. Trigonometry had not yet been invented.

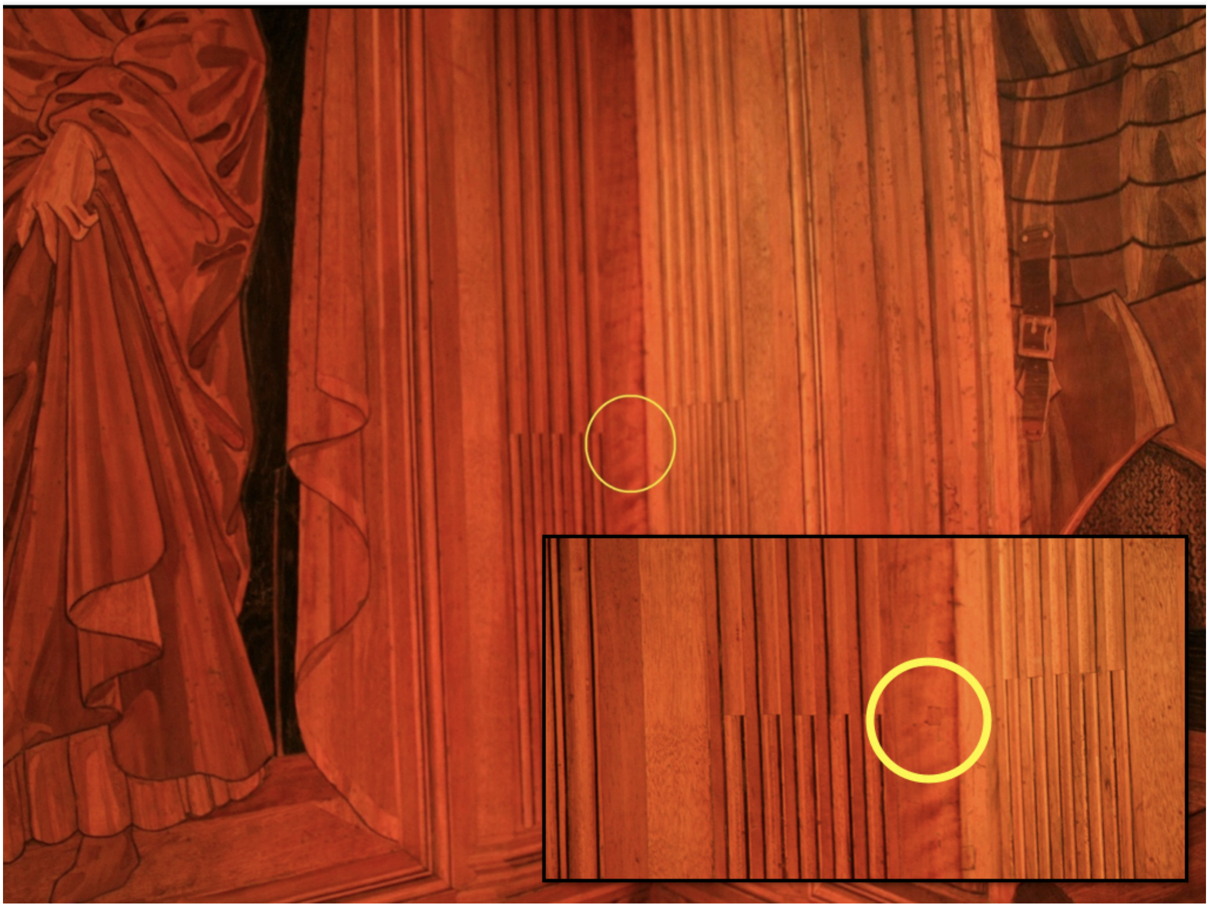

Fig. 11. Presence of a wooden patch at the proposed distance point on the north wall of the *studiolo*. General view and close-up

Technical drawings of the 'real' instrument

Henceforth, the process is simple: it consists merely of systematically reversing Alberti's perspective rules. We will now reconstruct the shape of the 'real' clavichord from its representation in perspective according to Alberti's rules. The major assumption of the present work is the following: it is assumed that the front panel of the clavichord intarsia represents the front panel of the 'real' instrument at a 1:1 scale. Hence, the case outer dimensions of the 'real' clavichord are estimated to be 1005 mm-R long, 216 mm-R wide and

82 mm-R deep.[6] The thickness of the case is approximately 12 mm-R. Fig 12 gives the main dimensions (in mm-R) of the 'real' clavichord determined accordingly.

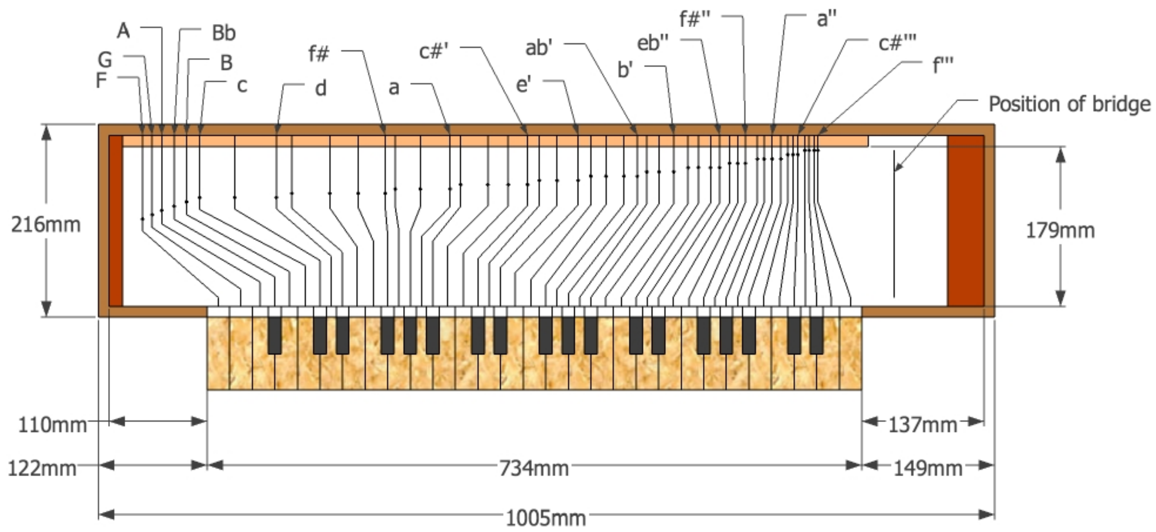

Fig. 12. Proposed plan view of the 'real' clavichord of the Urbino intarsia.
Measurements are expressed in mm-R

Table 2 below compares the dimensional ratios of the Urbino clavichord with the proportions mentioned in two well-known treatises, Arnaut de Zwolle and the French treatise MS Geneva Lat. 80, *Volens facere clavichordium*.[7]

	Length/width	**Height/width**	**Soundboard height/ width**
Urbino clavichord (present work)	14/3	1/2.26	1/4
Arnaut de Zwolle *secundum librum Baudeceti*	14/3	1/2	1/6
Geneva MS Lat. 80 *Volens facere clavichordium*	15/3	–	1/9

Table 2. Main dimensional ratios

[6] In the entrance hall of the town hall of Urbino, there is a panel labelled *'Misure lineari e di superficie della Città XV secolo'* to which are affixed iron bars reporting allegedly the local units of measurements in the fifteenth century: lengths and surfaces. The lengths, eight in number, are as follows, with their respective marks, read from left to right: B 697 mm; ME 998 mm; P 356 mm; no mark 362 mm; no mark 362 mm; M 350 mm; SETA [silk] 584 mm; LANA [wool] 657 mm. The meaning of the marks associated with six of the iron bars is unknown and has not been examined further. Interestingly enough, it seems that none of those units or any of their simple multiples or divisions were used for building the clavichord represented in the studiolo. This is certainly worth further study. The question of measurement units is entirely open.

[7] See Bernard Brauchli, *The Clavichord* (Cambridge: Cambridge University Press, 1998), pp. 28–34 (Arnaut) and pp. 38–9 (Geneva Lat. 80).

The ‘real’ sounding lengths of strings can be assessed extremely accurately from our measurements on the intarsia. The absolute uncertainties are estimated to be no larger than one to two millimetres. The relative errors, i.e. the differences between string lengths, are even smaller; these differences can be estimated with accuracy better than one millimetre. Tables 3 and 4 provide detailed data, respectively for the slot positions on the ‘real’ rack, measured from the right-hand wall, and for the string lengths measured from the bridge position, i.e. the sounding lengths. The sounding length of the note c^2 of the third octave is approximately 227.5 mm-R.

Rounded figures; tolerances: +/– 1 millimetre
Right-hand internal corner to bridge: 101 mm-R

Note	**Position mm-R**	**Note**	**Position mm-R**	**Note**	**Position mm-R**	**Note**	**Position mm-R**
f^3	180.5	f^2	270.5	f^1	437.5	f	699.0
e^3	186.0	e^2	280.0	e^1	449.5	e	731.0
$e\flat^3$	192.5	$e\flat^2$	291.0	$e\flat^1$	474.0	e♭	774.0
d^3	199.0	d^2	302.5	d^1	495.5	d	788.0
$c\#^3$	203.0	$c\#^2$	317.5	$c\#^1$	506.0	c#	836.0
c^3	210.5	c^2	328.5	c^1	528.5	c	875.5
b^2	217.0	b^1	342.5	b	549.0	B	888.5
$b\flat^2$	226.5	$b\flat^1$	357.5	b♭	582.0	B♭	902.5
a^2	232.0	a^1	371.0	a	593.0	A	916.5
$a\flat^2$	241.5	$a\flat^1$	383.0	a♭	627.0	G	927.0
g^2	251.0	g^1	398.0	g	655.0	F	938.0
$f\#^2$	262.0	$f\#^1$	420.5	f#	665.5		

Table 3. Slot positions on the ‘real’ rack, in mm-R from the right-hand case wall

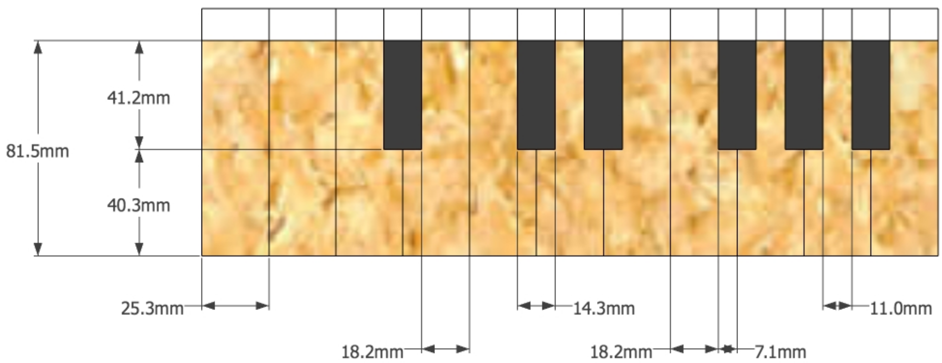

Fig. 13. Main dimensions of keys proposed for the ‘real’ clavichord, expressed in mm-R

Rounded figures; tolerances: +/– 1 millimetre

Note	String length mm-R	Note	String length mm-R	Note	String length mm-R	Note	String length mm-R
f^3	79.5	f^2	169.5	f^1	336.5	f	598.0
e^3	85.0	e^2	179.5	e^1	348.5	e	630.0
$e♭^3$	91.5	$e♭^2$	190.0	$e♭^1$	373.0	e♭	673.0
d^3	98.0	d^2	202.0	d^1	394.5	d	687.0
$c\#^3$	102.0	$c\#^2$	216.5	$c\#^1$	405.0	c#	735.0
c^3	109.5	***c^2***	***227.5***	c^1	427.5	c	774.5
b^2	116.0	b^1	241.5	b	448.0	B	787.5
$b♭^2$	125.5	$b♭^1$	256.5	b♭	481.5	B♭	801.5
a^2	131.0	a^1	270.5	a	492.0	A	815.5
$a♭^2$	140.5	$a♭^1$	282.0	a♭	526.0	G	826.0
g^2	150.5	g^1	297.0	g	554.0	F	837.0
$f\#^2$	161.0	$f\#^1$	319.5	f#	565.0		

Table 4. Sounding string lengths on the 'real' clavichord, in mm-R from the bridge

Fig. 13 provides details of the keyboard for the 'real' instrument. The width of the naturals is 25.3 mm-R, which is very close to the 25.5 mm key width determined for the organ painted *c.* 1432 on the Ghent altarpiece.[8] The octave span of the clavichord is 177.5 mm-R, its Stichmass 532.0 mm-R. The bridge is represented with great accuracy as well: Fig. 14 gives the lateral dimensions of the viol-shaped bridge. Its thickness at the foot is approximately ten millimetres.

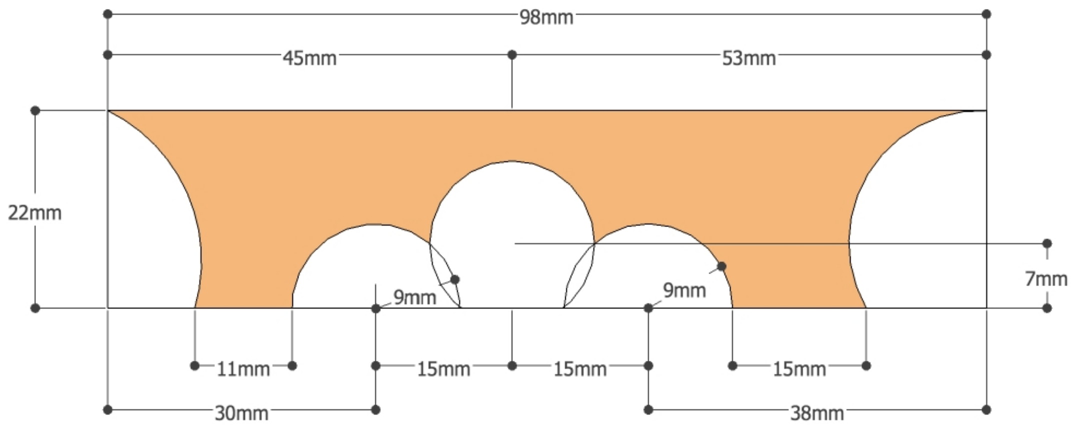

Fig. 14. Lateral dimensions proposed for the bridge of the 'real' clavichord, expressed in mm-R

[8] Martin-Knud Kaufmann, 'Le clavier à balancier du clavisimbalum (XVe siècle)', *La Facture de Clavecin du XVe au XVIIIe siècle* (1976), Musicologica Neolovaniensia. Studia 1 (Louvain-la-Neuve, 1980), pp. 9–57.

Fretting scheme

Except for the lower half-octave, the fretting is regular: 3–4–3–4 etc. Two tangents are missing in the top octave, for the notes $b\flat^2$ and $c\#^3$. It is proposed to restore them by simply continuing the sequence 3–4–3–4, and thus to allocate the tangent for $b\flat^2$ to a group of four, together with a^2, $a\flat^2$ and g^2; and to allocate the tangent of $c\#^3$ to a group of three, together with b^2 and c^3. See Fig. 15.

octave c3-f3	octave c3-c2	octave c2-c1	octave c1-c and lower
	c#3 ? tangent missing		
	c3		
	b2	b1	
	bb2 ? tangent missing	bb1	
	a2	a1	a
	ab2	ab1	ab
	g2	g1	g
	f#2	f#1	f#
f3	f2	f1	f
e3	e2	e1	e
eb3	eb2	eb1	eb
d3	d2	d1	d
	c#2	c#1	c#
	c2	c1	c
		b	B
		bb	Bb
			A
			G
			F

Fig. 15. Fretting scheme of the clavichord in the Urbino intarsia

These attributions are logical and answer to a sort of rebus proposed by the intarsia. We are inclined to believe that the fact that two tangents are missing is not due to an accidental omission. This anomaly, in our view, is not fortuitous. Be that as it may, in practical terms, it means actually that this clavichord is not in playable order. This fact has not been reported earlier, as far as we know. Another intriguing issue is that the tuning pins are thirty-six in number, while there are only thirty-four strings for seventeen courses. It is clear, from the detailed measurements and the fretting scheme, that the instrument was designed to accommodate only seventeen string courses and not eighteen. Two tuning pins are clearly in excess. Here also, we tend to think that this anomaly is not due to a mistake. Everything in the *studiolo* has a meaning. Let us mention another anomaly, just adjacent. The lute immediately to the left of the clavichord also shows an interesting feature, as two of its strings are broken. The lute is not in playable condition. These peculiarities raise questions about the exact symbolism of those unplayable musical instruments amidst the formal perfection of the *studiolo*.

String lengths, clavichord scaling, intonation

Let us revert to the quantitative analysis of the clavichord. The graph in Fig. 16 shows the scaling of the clavichord together with the theoretical Pythagorean scaling equivalent for c^1. When comparing the theoretical line with the measured scaling, it appears that the measured points are close to the theoretical line from f^3 to a, but deviate progressively for the notes at the lower octave. Therefore the strings were certainly not tuned in unison.

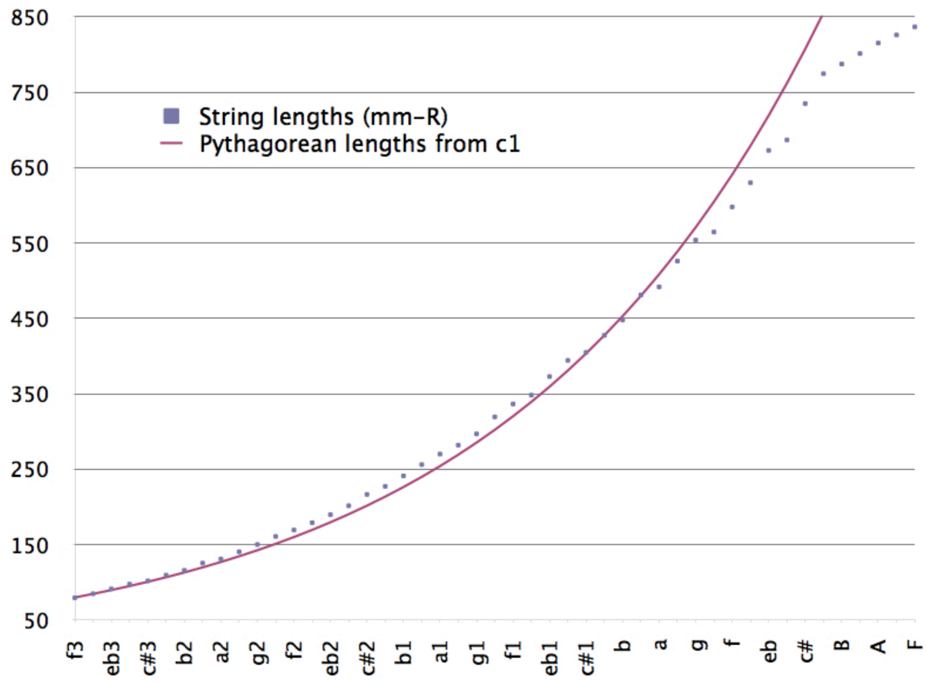

Fig. 16. Reconstructed string lengths expressed in mm-I compared with Pythagorean lengths calculated from note c^1

With the knowledge of the string lengths, the original tuning system of the 'real' instrument can be estimated confidently. The analysis suggests that it is in Pythagorean intonation, the temperament which one would indeed expect to find on an instrument of the fifteenth century. We will now demonstrate this. It is well known that, in this temperament, all fifths are pure except a the wolf fifth. In the case of the Urbino clavichord, it can be demonstrated that the wolf fifth is on the interval B–F#. The 'B × F#' disposition', as Mark Lindley called it a few decades ago,[9] was prescribed by Arnaut *secundum librum Baudeceti* and by other theorists.

Table 5 below shows for reference the theoretical values of intervals for semitones and tones in this B × F# disposition. For example, two types of semitones appear whose distribution among the pairs of notes is an indication of the intonation system. A similar comment applies for the whole tones, for the minor thirds, and for any larger interval which would belong to the same set of fretted notes. The purpose of this table is to provide the tools required to compare theoretical values with data collected from the Urbino intarsia, which are shown on the next graph.

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[9] Mark Lindley, 'Pythagorean intonation', *The New Grove Dictionary of Music and Musicians*, 1980.

All fifths pure except the wolf fifth on B–F#

Semitone	Interval (cents)	Tone	Interval (cents)
F–E	90.2	F–E♭	203.9
E–E♭	113.7	E–D	203.9
E♭–D	90.2	E♭–C#	203.9
D–C#	113.7	D–C	203.9
C#–C	90.2	C#–B	180.4
C–B	90.2	C–B♭	203.9
B–B♭	113.7	B–A	203.9
B♭–A	90.2	B♭–A♭	203.9
A–A♭	113.7	A–G	203.9
A♭–G	90.2	A♭–F#	203.9
G–F#	113.7	G–F	203.9
F#–F	90.2	F#–E	180.4

Table 5. Determination of intonation, semitones and tones in Pythagorean tuning with B × F# disposition

On the graph in Fig. 17 are plotted the values in cents of the semitones for all fretted notes measured on the Urbino clavichord. These values are directly derived from the sounding string lengths reported in Table 4 above. On this graph, one clearly distinguishes two different sets of intervals: one for large semitones, the diatonic semitones or *apotomē* at 113.7 cents, and the other for small semitones, the chromatic semitones or *limma* at 90.2 cents. Detailed examination of the graph shows that the distinction between large semitones and small semitones closely follows the pattern we have just seen in Table 5 for Pythagorean tuning in the B × F# disposition.

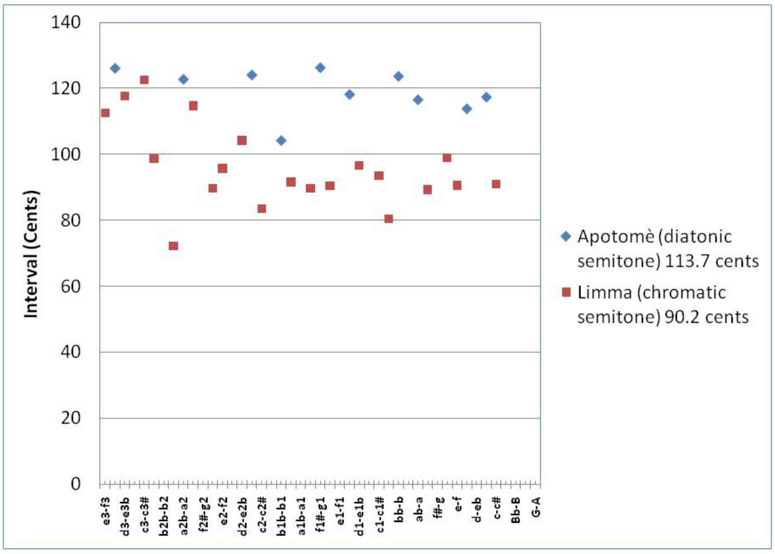

Fig. 17. Values of semitones for all pairs of fretted notes, as deduced from the reconstructed string lengths of the clavichord in the Urbino intarsia, expressed in cents

The correspondence is good in the treble but apparently deteriorates in the top octave. This is a sort of artefact, almost certainly due to small unavoidable uncertainties when measuring the rack dimensions on the intarsia, or to the accuracy of the intarsia itself. Very small uncertainties on these measurements for the short strings lead immediately to noticeable uncertainties on graphs like this one.

A similar graph can be drawn for whole tones. Here also, a distinction is observed between the two types of intervals, although it is less clear than for semitones. Eventually, a third graph may be drawn for the minor thirds, where there are only a few points, from which no useful information may be gathered. Many conclusions can be drawn from this analysis, including naturally that the temperament of the 'real' instrument is the Pythagorean intonation with the B × F# disposition. It is also worth noticing that the craftsmen who made this marquetry had a profound knowledge of what the rack of a clavichord actually is. As Bernard Brauchli mentioned in his monograph on the clavichord, one might wonder whether the intarsia wouldn't have specifically served to illustrate the Pythagorean tuning system.[10]

Concluding remarks

We will not draw any generic conclusion in addition to the specific points which have been mentioned above. A number of questions deserve further study, such as: what precise relationship exists to earlier designs, such as Arnaut's? Has the Urbino clavichord had an influence on the making of Italian keyboard instruments of the sixteenth century, including those of the famous master Lorenzo Gunasco da Pavia, who served at the Urbino court in 1505? What was the iconographic role of the clavichord in the *studiolo* of Duke Federico?

Acknowledgements

The author wishes to acknowledge the support, assistance and co-operation of Dr.ssa Vittoria Garibaldi, Sopraintendente, Soprintendenza per i Beni Storici, Artistici ed Etnoantropologici delle Marche; Dr.ssa Agnese Vastano, Direttore storico dell'arte, Urbino, Soprintendenza per i Beni Storici, Artistici ed Etnoantropologici delle Marche; Sig. Massimo Fabbri, Ufficio Tecnico, Soprintendenza per i Beni Storici, Artistici ed Etnoantropologici delle Marche; Bernard Brauchli, performer, musicologist, president of Musica Antiqua a Magnano; Peter Bavington, clavichord maker, chairman of the British Clavichord Society; Didier Jarny, luthier, secrétaire adjoint de l'Association Française du Luth.

Abstract

The paper provides new measurements, drawings and photographs of the clavichord in the Urbino intarsia (c. 1479), including details unpublished until now, together with accurate dimensional measurements. This paper shows how the perspective of the studiolo can be reversed and how the dimensions of the 'real' clavichord can be determined with a high level of certainty. It is demonstrated that the perspective drawn by Baccio Pontelli in 1479 is perfect: there is no need to postulate either any distortion of perspective or the co-existence of different types of perspectives. The author deduces from the new measurements of the intarsia the dimensions of the 'real' clavichord: outer and inner dimensions, rack, keyboard, bridge, etc. Some dimensions published previously need to be amended. The paper ends with conclusions with respect to organological issues about the Urbino clavichord: regular fretting 3–4, Pythagorean temperament.

[10] Bernard Brauchli, *The Clavichord*, p. 36.