

# The Urbino clavichord revisited

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## Summary

The paper provides new measurements, drawings and photographs of the clavichord on the Urbino intarsia (ca. 1479), including details unpublished until now, together with accurate dimensional measures. This contribution 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 neither any distortion of perspective nor the co-existence of different types of perspectives. The author deduces from the new measurements 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 re. the Urbino clavichord: regular fretting 3-4, Pythagorean temperament.

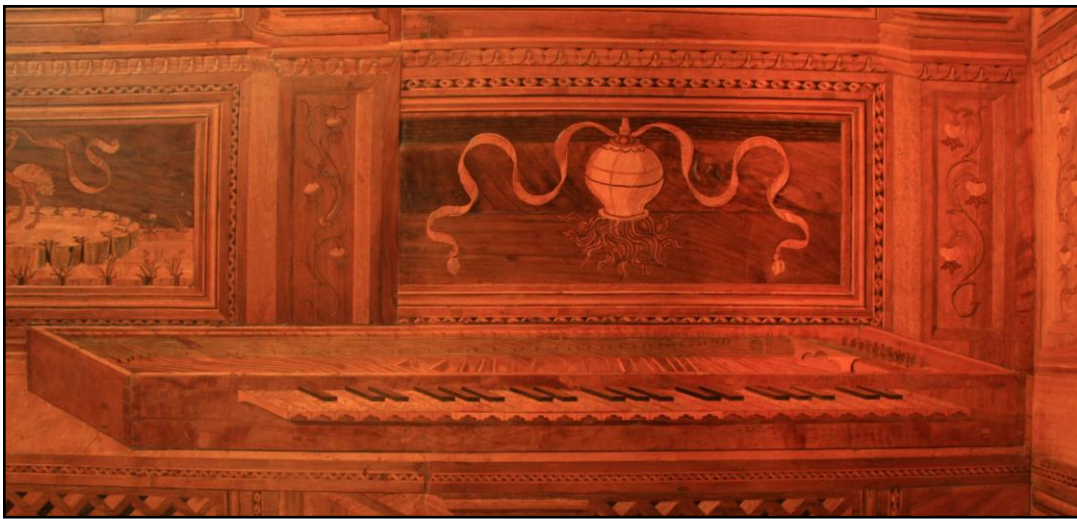


Figure 1: Workshop of Baccio Pontelli. Clavichord (c. 1479). Palazzo Ducale, Urbino. Normal view.

## Introduction

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

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<sup>2</sup>.

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The construction of the Ducal palace at Urbino, which started *ca.* 1450 and ended *ca.* 1582, was the result of a wonderful conjunction between the intelligence & the money of the 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, the Duke Federico da Montefeltro builds an image of himself and shows it to others. This room is a seminal location of the first Italian Renaissance. With the 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 *studiolo* is a small irregular room, nearly square, about 12 square meters, in a half-light, where one is surprised altogether by the abundance of decoration and by the darkness of the place, only lightened by one rather small window. The paintings of the *Famous Man* on upper part of the *studiolo* walls are by Giusto di Gand (*Juste de Gand*) 1473 –1475: twenty-eight portraits of illustrious Men: Albertus, Dante, Petrarch, Moses, Solomon, Plato, Aristotle, Ptolemy, Cicero, Homer, Virgil, Euclid, and others. The intarsia underneath the paintings is made by the best cabinet maker of the time, Baccio Pontelli (*ca.* 1450-1492). He allegedly used designs of Sandro Botticelli or other prominent artists around Duke Federico.

A first glance, the objects depicted on the intarsia are in a disorder: the whole room seems to be a collection of disparate pieces of art, gathered together randomly, seemingly just in order to show how the Duke lived in private. But it is now known that the *studiolo* is not made at random: it has a very specific iconographic program<sup>3</sup>. The clavichord on the North wall of the *studiolo* plays a role in that iconographic program. 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 an 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 x 216 mm x 82 mm without keyboard ( $\pm 1$  mm). Its wall thickness is twelve millimetres ( $\pm 0.5$  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 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 bridge and tangents’ positions, 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

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<sup>2</sup> Edwin M. Ripin, ‘*The Early Clavichord*’, *The Musical Quarterly*, 53/4 (1967): 518-538; Angelo Mondino, ‘*Il Clavicordo – Interpretazione e Ricostruzione di Antichi Strumenti a Tastiera*’, Coll. *Musica Ragionata*, 5, Libreria Musicale Italiana Editrice, Lucca, 1993; Denzil Wraight, ‘*The stringing of Italian keyboard instruments c. 1500- c. 1650*’, Ph.D. dissertation, Queen’s University of Belfast, 1997.

<sup>3</sup> Daniel Arasse, ‘*Frédéric dans son cabinet : le Studiolo d’Urbino*’, *Le sujet dans le tableau, essai d’iconographie analytique*, Champs arts, Paris 1997, 2006: 27-55

thirty-six tuning pins. All tangents are in the form of cramps. Two tangents are missing. The fretting scheme is 3-4-3-4... consistently after the bass octave. The temperament is Pythagorean tuning, with wolf's fifth on B-F#. The pitch might have been  $a^2 = 440$  Hz or higher.

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

### **Technical drawings of clavichord on the intarsia**

Everything in the *studiolo* looks three-dimensional but everything is flat surface. The *trompe-l'oeil* is of such a 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 make confusion between the representation of the objects and the objects themselves. The excellence of the *trompe-l'oeil* 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 a 'contamination' of those basic measurements with any preconception for the 3D real instrument. For communication purposes, it is suggested here to use the following vocabulary convention. We will use *mm-I* for the 2D representation and *mm-R* for the 3D interpretation. In the course of the discussion hereinafter, this convention shall prove useful.

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 meters wide and three & a half meters long. The North wall faces the visitor when entering through the South door. The visitor makes a few steps and then stops, after one meter and a half, at exactly 2.7 meters in front of the North wall. Now he/she sees the marquetry on the wall as if it was 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 lays on a shelf in the right corner, just under the portrait of Federico. The apparent height of the shelf is approximately sixty-five centimetres. The apparent length of clavichord is approximately one meter. The closer one comes to the instrument, the lesser it looks like a real instrument. It gets distorted. Anamorphic effects begin to modify the visual perception. The distortion is very significant, for example, when one walks to the right corner and has a *perpendicular* look at the clavichord at the surface. This is the so-called "normal view".

### **Normal view: main dimensions of clavichord on intarsia**

Fig. 1 provides a photograph close to the "normal view" of the clavichord. Remember that this only a flat surface. Wealth of measurements have been made on that flat surface<sup>4</sup>. Our conventional measurement tool 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 walls of the clavichord are rather thick, twelve millimetres. Note that such measurements

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

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 calliper. The tolerance for the longer dimensions can be estimated to be around one millimetre. For shorter dimensions, the tolerance is estimated to be approximately one-half millimetre.

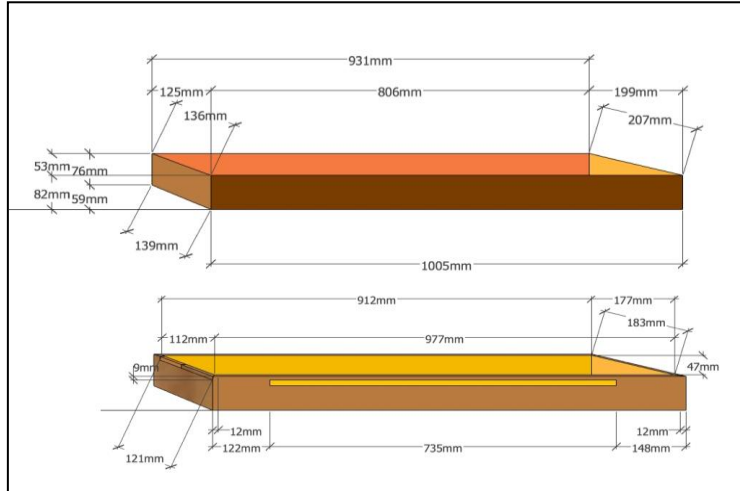


Figure 2: Main external (top) and internal (bottom) dimensions measured on the clavichord representation, expressed in mm-I.

After having determined the main outer and inner dimensions, all details can be measured as well, with similar measurement tolerances. Fig. 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 bridge or any other item, contrarily to what was assumed by some scholars.

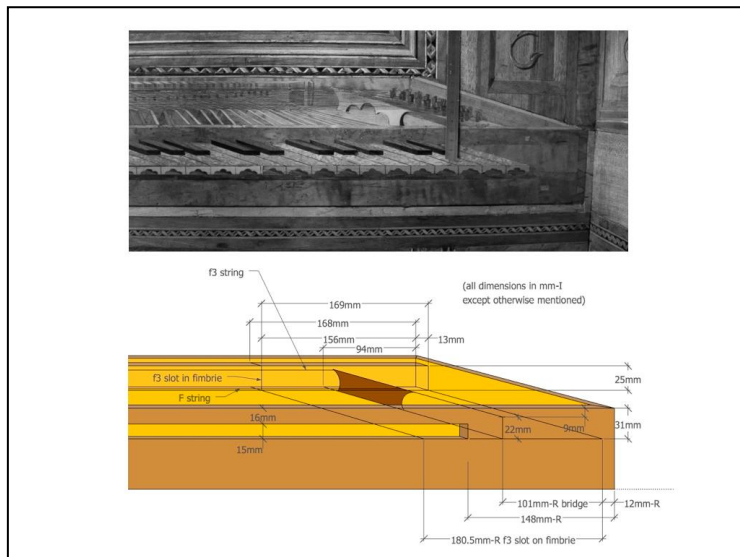


Figure 3: Position and main dimensions of bridge, soundboard and rack measured on the clavichord representation, expressed in mm-I.

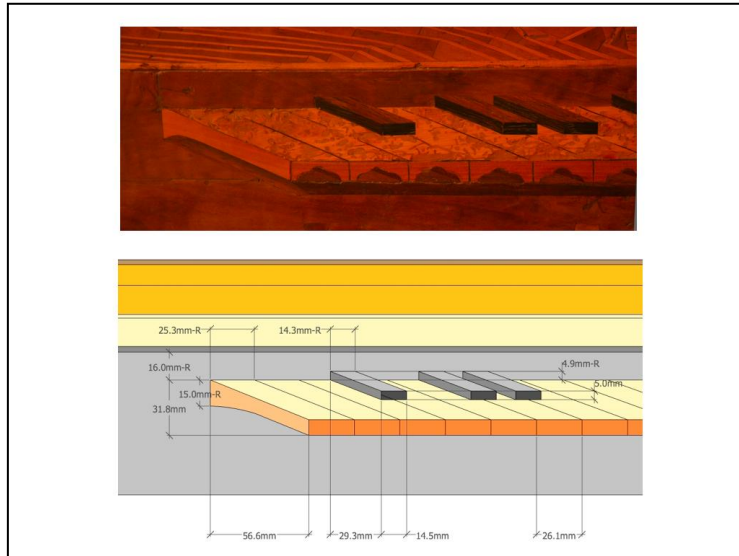


Figure 4: Main dimensions of keys measured on the clavichord representation, expressed in mm-I.

The keyboard extends from F to f3. 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 tortoise shell. Decorative gothic arcades cover the end of the keylevers. 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 get fingers between two sharps.

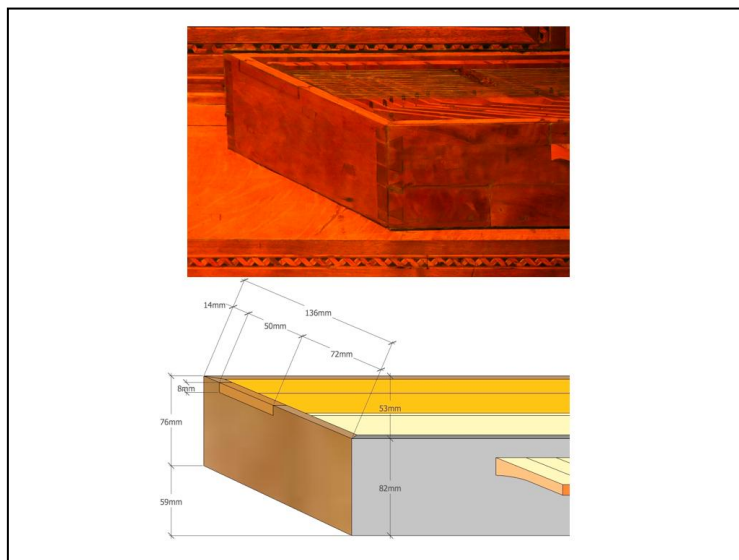


Figure 5: Hitchpin cover block on the left wall of case. Measurements made on the clavichord representation, expressed in mm-I.

## Hitchpin cover block

Fig. 5 shows a very peculiar observation on 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 on Fig. 5 shows all measures in mm-I. It seems to make sense to imagine that some (or all) hitch-pins would have been driven directly in the left-hand case side. 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 case, at a place invisible on the intarsia.

## Slot positions on the rack

The measurements made on the representation of the rack are obviously most important if one wishes to analyze the intonation of the ‘real clavichord’. There are many ways to measure the slot positions. For practical reasons and for the sake of obtaining 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 apparent distance between the right-end corner and the right-end apparent edge of the slot, starting with the bridge. Horizontally, the measurements were made along the apparent last string, which draws a very clear straight line.

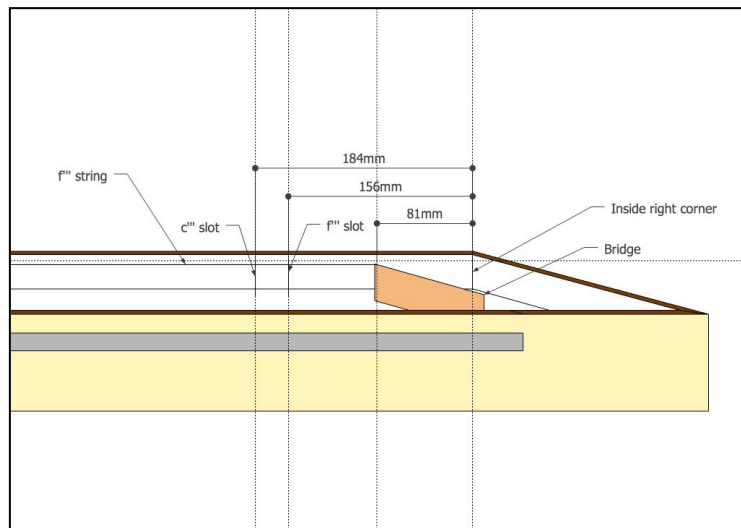


Figure 6: Method used for measuring slot positions on the rack of the clavichord representation. Dimensions expressed in mm-I.

As Fig. 6 shows, the apparent coordinate of the bridge is determined to be 81 mm-I from the apparent right-end corner. The apparent coordinate of the first slot, for  $f^3$ , is 156 mm-I, of the second slot, 161 mm-I, etc. Table 1 hereinafter 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 mm.

*Table 1: slot positions on the rack, as measured, mm-I from right corner – see text – tolerances +/- 1 mm*

note	position mm-I	note	position mm-I	note	position mm-I	note	position mm-I
f <sup>3</sup>	156	f <sup>2</sup>	240	f <sup>1</sup>	396	f	640
e <sup>3</sup>	161	e <sup>2</sup>	249	e <sup>1</sup>	407	e	670
eb <sup>3</sup>	167	eb <sup>2</sup>	259	eb <sup>1</sup>	430	eb	710
d <sup>3</sup>	173	d <sup>2</sup>	270	d <sup>1</sup>	450	d	723
c# <sup>3</sup>	177	c# <sup>2</sup>	284	c# <sup>1</sup>	460	c#	768
c <sup>3</sup>	184	c <sup>2</sup>	294	c <sup>1</sup>	481	c	805
b <sup>2</sup>	190	b <sup>1</sup>	307	b	500	B	817
bb <sup>2</sup>	199	bb <sup>1</sup>	321	bb	531	Bb	830
a <sup>2</sup>	204	a <sup>1</sup>	334	a	541	A	843
ab <sup>2</sup>	213	ab <sup>1</sup>	345	ab	573	G	853
g <sup>2</sup>	222	g <sup>1</sup>	359	g	599	F	863
f# <sup>2</sup>	232	f# <sup>1</sup>	380	f#	609		<i>bridge 81 mm-I</i>

### 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 the central perspective. Filippo Brunelleschi was a genial experimenter. Leon Battista Alberti was more a mathematician. Both of them described essentially the same process. This process, called the central perspective, had a profound influence on the 2D representation of 3D realities, from the middle Quattrocento until today. The mathematician Alberti will be our guide for understanding and then reversing the perspective of the clavichord in Federico’s *studiolo*.

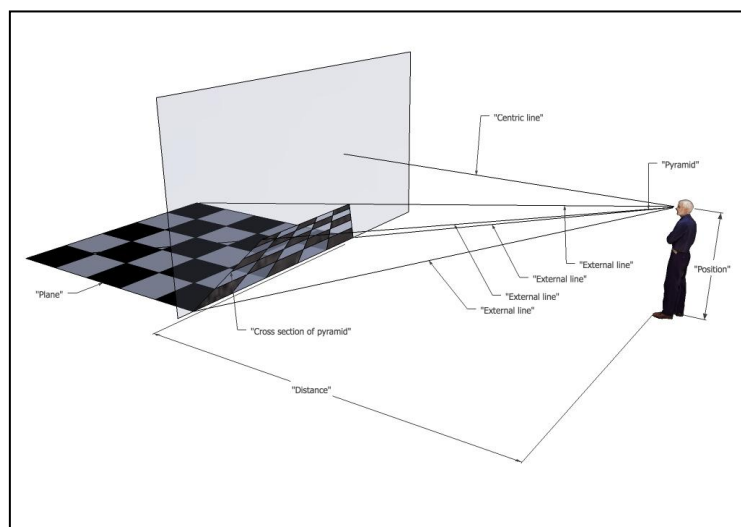


Figure 7: Principle of Alberti's perspective construction as described in *Della pittura* (1435-6).

We will follow closely the geometrical considerations of Leon Battista Alberti in his well known treaty ‘*On Painting*’ published almost simultaneously in Italian and in Latin. This book has no drawing. The drawing on Fig. 7 restates Alberti’s perspective construction in a modern way. The



## Reversal of the central perspective of North wall of Federico's *studiolo*

The method summarized above is the one which has been 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.

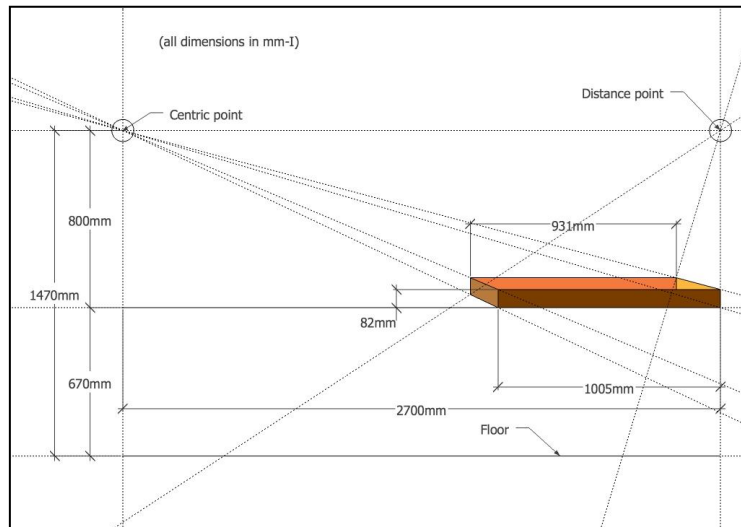


Figure 9: Proposed reconstructed central perspective of the North wall of Federico's *studiolo* of Urbino. Measures expressed in mm-I.

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 after, 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 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 others.

Applying those criteria and using measurements and photographs of the North wall, we concluded that the distance point was just in the North-East corner, at the right of Federico's portrait and at the height of the centric point, approximately 1.47 meters 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 objects, 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 must be made to reconstruct this central perspective. There is no need to invoke complicated proportional triangles nor conflicting parallel perspective nor any complication of that type. It is a simple and rigorous application of the Alberti's perspective.

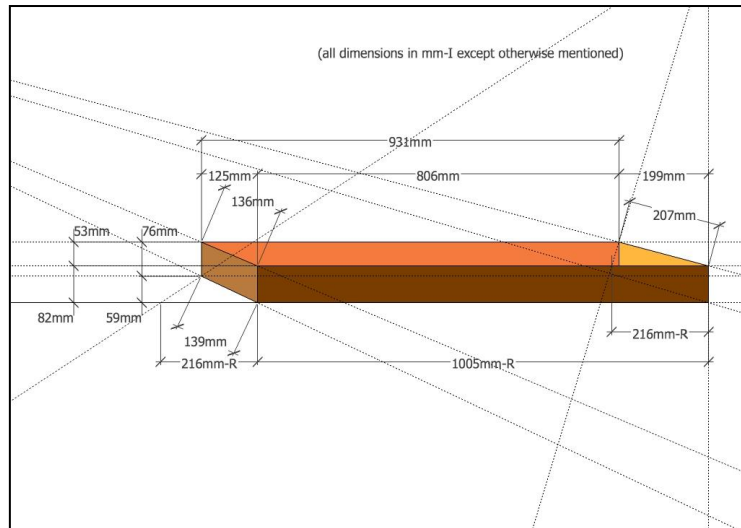


Figure 10: Proposed reconstruction of the 'real' clavichord width.  
Measures expressed in mm-I unless otherwise mentioned.

An *indirect* proof is given by considering the dimensions of the shelf at the left of the clavichord. At the middle of the North wall, there is a shelf which is 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 (166mm-I, tolerances +/- 5 mm). Accurate measurements of that sort show that the distance point and the centric point assumed here are right.

A *direct* proof is given by the observation of the existence of a wooden patch on the intarsia at the distance point. Indeed, when looking at the point where the distance point is supposed to be, one finds a very small piece of wood inserted in the intarsia. Fig. 11 shows the location of that piece of wood and a close-up of same. It is believed that this wooden patch had the function of covering and hiding the hole of a nail which was used for drawing the construction lines of intarsia.

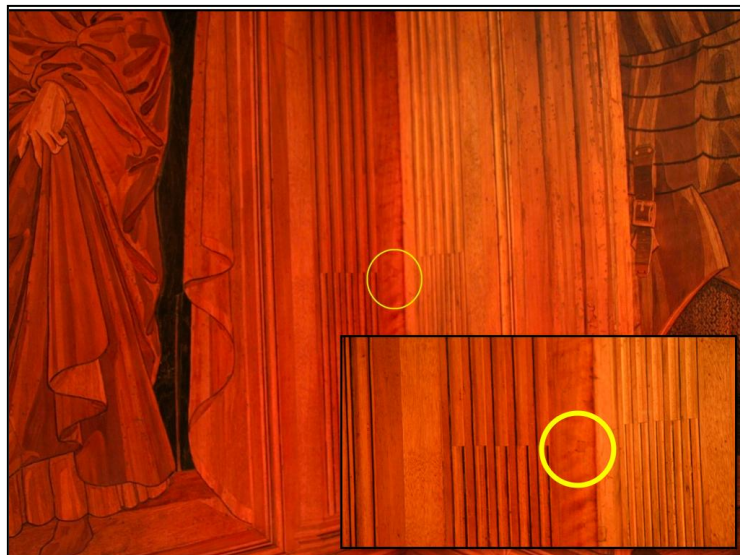


Figure 11: Presence of a wooden patch at the proposed distance point on North wall of Federico's studiolo. General view and close-up.

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. The objects can be represented precisely. The intarsia of Urbino shows other wooden patches having a similar purpose, as aides for

drawing open doors of cabinets, shelves, armour, books, astronomical instruments, and others. The purpose of the wooden patch would have been to cover and hide the hole of a nail used for drawing the construction lines of intarsia. 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 calculation work. The Quattrocento engineers used geometry, not algebra. Trigonometry was not yet invented.

### Technical drawings of the ‘real’ instrument

Henceforth, the process is simple: it consists merely of reversing systematically 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 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<sup>6</sup>. The thickness of the case is about 12 mm-R. Fig 12 gives the main dimensions of the ‘real’ clavichord determined accordingly (all dimensions in mm-R).

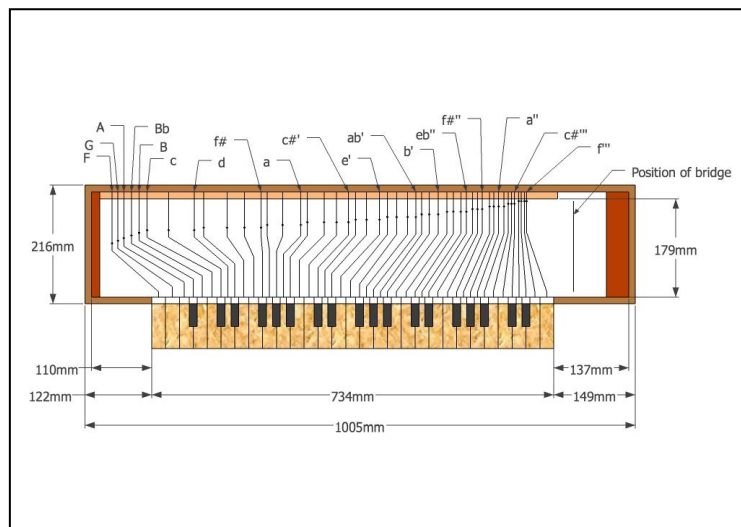


Figure 12: Proposed plan view of the ‘real’ clavichord of the Urbino intarsia.

Table 2 below compares the dimensional ratios of the Urbino clavichord with the proportions mentioned in two well-known treatises.

<sup>6</sup> 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 584 mm; LANA 657 mm. The meaning of the marks associated with six of the iron bars is unknown and has not been examined further. Interestingly enough, there seems that none of those units or any of their simple multiple or divisions seem to have been used for building the clavichord represented in the studiolo. This certainly is worth being studied. The question of measurements units is entirely open.

*Table 2 : Main dimensional ratios – L/W length / width, H/W height / width, SH/W soundboard height / width*

	L/W	H/W	SH/W
Urbino clavichord (present work)	14/3	1/2.26	1/4
Arnaut de Zwolle <i>secundum librum Baudeceti</i>	14/3	1/2	1/6
Geneva MS 80 <i>Volens facere clavichordium</i>	15/3	-	1/9

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 of 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 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.

*Table 3 : Slot positions on the ‘real’ rack, in mm-R from the right case wall, rounded figures, tolerances +/- 1 millimetre*

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
$eb^3$	192.5	$eb^2$	291.0	$eb^1$	474.0	eb	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
$bb^2$	226.5	$bb^1$	357.5	bb	582.0	Bb	902.5
$a^2$	232.0	$a^1$	371.0	a	593.0	A	916.5
$ab^2$	241.5	$ab^1$	383.0	ab	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	bridge	101 mm-R

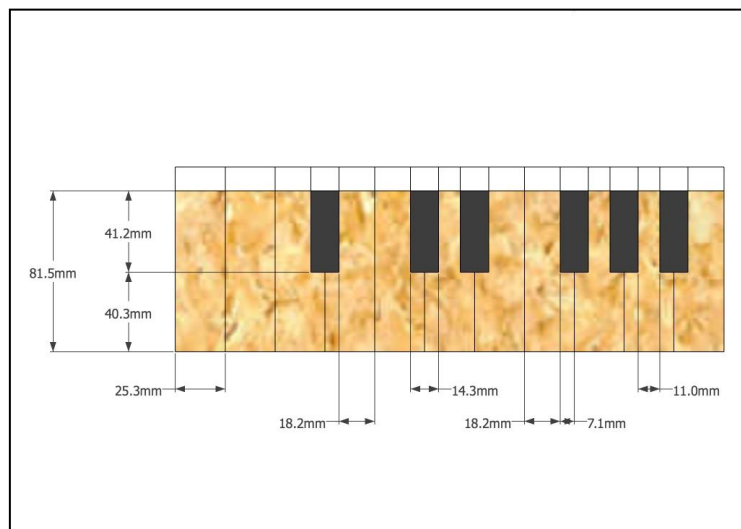


Figure 13: Main dimensions of keys proposed for the ‘real’ clavichord, expressed in mm-R.

*Table 4 : Sounding string lengths on the ‘real’ clavichord, in mm-R from the bridge, 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 <sup>3</sup>	79.5	f <sup>2</sup>	169.5	f <sup>1</sup>	336.5	f	598.0
e <sup>3</sup>	85.0	e <sup>2</sup>	179.5	e <sup>1</sup>	348.5	e	630.0
eb <sup>3</sup>	91.5	eb <sup>2</sup>	190.0	eb <sup>1</sup>	373.0	eb	673.0
d <sup>3</sup>	98.0	d <sup>2</sup>	202.0	d <sup>1</sup>	394.5	d	687.0
c# <sup>3</sup>	102.0	c# <sup>2</sup>	216.5	c# <sup>1</sup>	405.0	c#	735.0
c <sup>3</sup>	109.5	c <sup>2</sup>	<b>227.5</b>	c <sup>1</sup>	427.5	c	774.5
b <sup>2</sup>	116.0	b <sup>1</sup>	241.5	b	448.0	B	787.5
bb <sup>2</sup>	125.5	bb <sup>1</sup>	256.5	bb	481.5	Bb	801.5
a <sup>2</sup>	131.0	a <sup>1</sup>	270.5	a	492.0	A	815.5
ab <sup>2</sup>	140.5	ab <sup>1</sup>	282.0	ab	526.0	G	826.0
g <sup>2</sup>	150.5	g <sup>1</sup>	297.0	g	554.0	F	837.0
f# <sup>2</sup>	161.0	f# <sup>1</sup>	319.5	f#	565.0		

Figure 13 provides details on 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 altar piece<sup>7</sup>. The octave span of the clavichord is 177.5 mm-R, the *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.

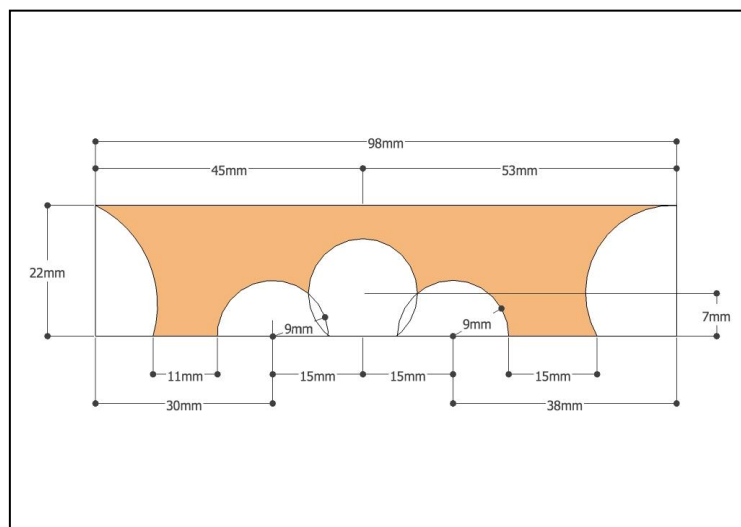


Figure 14: Lateral dimensions proposed for the bridge of the ‘real’ clavichord, expressed in mm-R.

<sup>7</sup> Martin-Knud Kaufmann, ‘‘Le clavier à balancier du clavisimbalum (XVe siècle)’’, La Facture de Clavecin du XVe au XVIIIe siècle, (1976), *Musnologica Neolovaniensia. Studia 1*, Louvain-la-Neuve, 1980: 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  $b^2$  flat and  $c^3$  sharp. It is suggested simply to continue the sequence 3-4-3-4 and thus to attribute the tangent for  $b^2$  flat to a group of four, together with  $a^2$ ,  $a^2$  flat and  $g^2$ . And to attribute the tangent of  $c^3$  sharp to a group of three, together with  $b^2$  and  $c^3$ . See Figure 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

Figure 15: Fretting scheme of the clavichord of 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 mistakes. Everything in the studiolo has a meaning. Let us mention another anomaly, just adjacent. The lute immediately at the left of the clavichord shows also an interesting feature, as two lute strings are broken. The lute is not in playable condition. Those peculiarities raise interrogation 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 on 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. The strings were certainly not tuned unison.

With the knowledge of string lengths, the original tuning system of the ‘real’ instrument can be estimated confidently. The analysis suggests that it is the 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 wolf's fifth. In the case of the Urbino clavichord, it can be demonstrated that the wolf's fifth is on the interval B–F#. The BxF# disposition, as Mark Lindley called it a few decades ago<sup>8</sup>, was prescribed by Arnaut *secundum librum Baudeceti* and by other theorists.

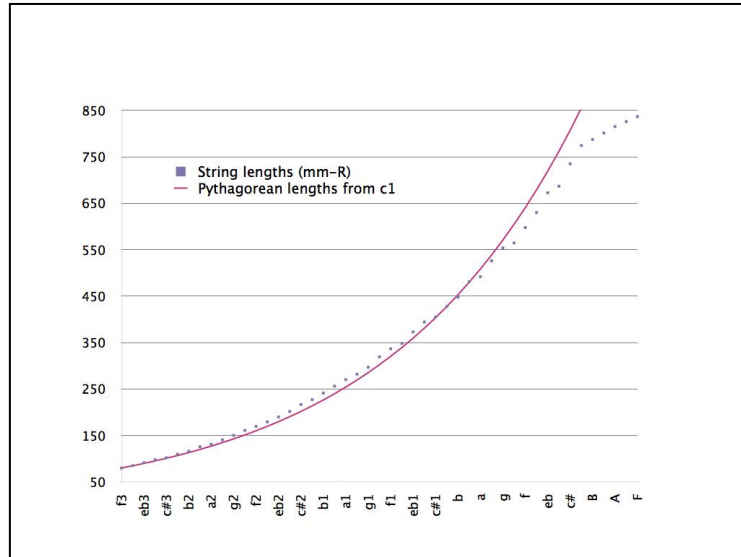


Figure 16: Reconstructed string lengths expressed in mm-I compared with Pythagorean lengths calculated from note c1.

Table 5 below shows for reference the theoretical values of intervals for semitones and tones in this BxF# disposition. For example, two types of semitones appear whose distribution among the couples of notes is a signature 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 graphs.

*Table 5: Determination of intonation, semitones and tones in Pythagorean tuning with BxF# disposition (all fifths pure except wolf's fifth on B-F#).*

Semitone	Interval (cents)	Tone	Interval (cents)
F-E	90.2	F-Eb	203.9
E-Eb	113.7	E-D	203.9
Eb-D	90.2	Eb-C#	203.9
D-C#	113.7	D-C	203.9
C#-C	90.2	C#-B	180.4
C-B	90.2	C-Bb	203.9
B-Bb	113.7	B-A	203.9
Bb-A	90.2	Bb-Ab	203.9
A-Ab	113.7	A-G	203.9
Ab-G	90.2	Ab-F#	203.9
G-F#	113.7	G-F	203.9
F#-F	90.2	F#-E	180.4

<sup>8</sup> Mark Lindley, "Pythagorean intonation", The New Grove Dictionary of Music and Musicians, 1980.

On the graph of 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 on Table 4 above. On this graph, one clearly distinguishes two different sets of intervals: one for large semitones, the diatonic semitones or *apotomè* 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 given in Table 5 we have just seen for Pythagorean tuning in the BxF# disposition.

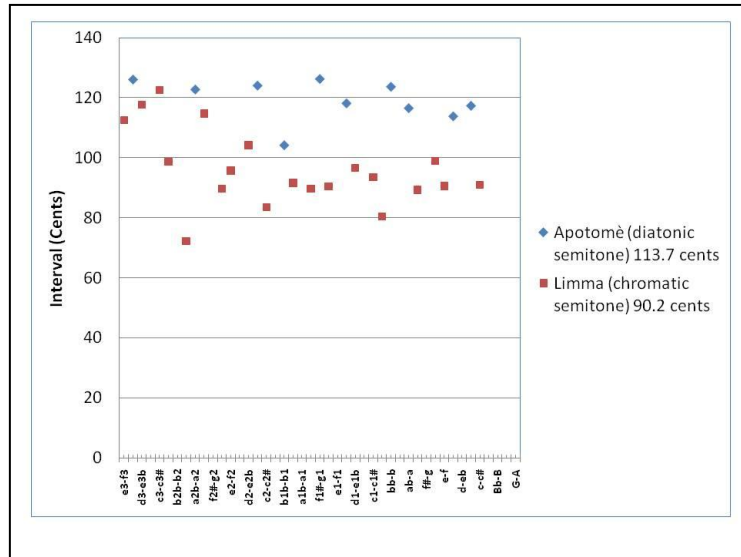


Figure 17: Values of semitones for all couples of fretted notes, as deduced from the reconstructed string lengths of the clavichord of the Urbino intarsia, expressed in cents.

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 those 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 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 BxF# disposition. It is also worth noticing that the craftsmen who made this marquetry had a profound knowledge of what a 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.

## 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 does exist 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 held service at the Urbino court in 1505? What precise iconographic role had 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, Soprintendente, Soprintendenza per i Beni Storici, Artistici ed Ethnoantropologici delle Marche; Dr.ssa Agnese Vastano, Direttore storico dell'arte, Urbino, Soprintendenza per i Beni Storici, Artistici ed Ethnoantropologici delle Marche; Sig. Massimo Fabbri, Ufficio Tecnico, Soprintendenza per i Beni Storici, Artistici ed Ethnoantropologici 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.