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SOUNDING WOOD

**Tonal differences of woods employed
in historical soundboards**

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Degree Project, Master of Fine Arts in Music,
Organ and related keyboard instrument

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ABSTRACT:

This work starts giving a short introduction about woodworking and devotes the second chapter to collecting and commenting historical sources dealing with wood used in stringed keyboard instruments. In the following part, looking both at sources and extant instruments, an approximate atlas of the wood types used in various building traditions is sketched; natural range and features of the most important trees used in soundboards are also given. A special kind of clavichord has been designed and built to test different soundboard materials without changing strings and bridge: pictures, together with a description of the instrument's genesis and technical features are provided in the fourth chapter. Physical measurements of the wood used in the sample soundboards and spectrum analysis of the recorded sound complete the work.

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Introduction

I. General foreword

The organ is a unique instrument in many ways. Not only because of its extremely variable size and appearance or its special role in the liturgy of many Christian Confessions: every *epoque* and every European nation gave the organ its very special construction and sound. Furthermore no other instrument has had such a long, quantitatively and qualitatively high, tradition of written music. So nowadays, giving the immense output of organ music written during the past 700 years, it's common for organists to specialize themselves in the segment of repertoire they prefer, which in turn requires a very well defined kind of organ.

It's hard to say what can guide the preferences of a young musician toward a certain repertoire, but for me it was an easy way to get completely fascinated by the Renaissance and Baroque instruments and their music. It may have played a role the fact that, early in my studies, I had to listen to a lot of of romantic and modern music played badly and on bad organs; anyway I felt immediately there was something very special about the sound of the earlier instruments. As a teenager I used to explain my subjective preferences with a similitude with seasons, which describes very much my aural sensations and my emotional attitudes: Renaissance organs sound to me like a mild, sunny spring; Baroque like a nice warm summer; late Romantic organ like a Swedish autumn and finally many modern instruments sounds as dead as an icy winter.¹

In the same way I immediately fell in love with the crisp and fresh sound of the harpsichord, which I instinctively opposed to the disappointing sound of the modern pianos I was forced to play before being allowed to start with the organ. Later I got so fascinated by the *Pedalclavichord* and its invaluable insights in the organ repertoire, that I immediately built one to be able to play it at home.

Since when I first started some specific courses on ancient music, at fourteen, especially on early Italian and South German repertoire, I was introduced in a world, where the boundaries between organ, harpsichord and clavichord music seldom were sharply defined, still each instrument had its own peculiar resources. I regard this approach to be very profitable: a keyboard player can learn the idiomatic language of each keyboard instrument and thanks to the different responses, he starts to focus and gain control over different aspects of the musical performance.

This is the kind of musical background that stands behind my present project and which gives it significance: when I have to talk about my work to people, which are not much involved in the world of historical keyboard instruments, the first feedback is almost always a question about its relevance to the musical performance. Since the sound is the goal of each musical instrument, I don't feel compelled to explain my interest on soundboards as an instrument builder, but I feel it is necessary to explain my point of view as musician.

After the very first years, while young musicians learn the basic skills of their craft, like reading music and playing more and more difficult pieces, a long and slow process of self-refinement starts, in which the instrument itself with its acoustical response is actually the main teacher. This learning process, done by careful listening, is perhaps the less spectacular part of the craft of playing an instrument, but it is indeed as necessary as learning to read scores. Sustain, decay and reverberation imposes rather definite limits to the player in terms of tempo and articulation; and if one is not willing to follow them while performing, the musical thoughts will become less and

¹ I do of course not claim any objectivity for this similitude. Still, since sensations and emotions are true for the person who is sensing them, it is at very least true for myself.

less understandable and recognizable for the audience. A spectacularly ingenious *Capriccio* by Frescobaldi can easily become boring, if played with inappropriate articulation, breathing and tempo just in the same way as a moving poem by Petrarca can simply become non-sense if declaimed with wrong accents, punctuation and speed. This is not surprising: since music is an art based on sound and time, tempo and every other aspect of temporally distributing the sound and silences is essential for performance. Indeed all these parameters are highly influenced by the instruments themselves.

Beside time, the other main ingredient of music is the sound itself: it is virtually unique to each particular instrument and impossible to copy exactly, just as the voice of a singer; still extremely interesting to study and compare. Sound (and noises) of an instrument are the main raw material of musical performances, just as cells are the basic elements of living creatures. Every organ player has had the experience of the same piece of music working astonishingly well on one instrument and badly on another; and every skilled improviser can tell that different sounds inspire different pieces. Still the influence that a certain sound had on composers and the complex interactions between instrument building and composing, are often underestimated, since they are impossible to quantify in an objective way and hard to demonstrate.

In my modest experience as player and composer, however, good instruments with their response and sound were always a primary source of inspiration, a reward for my efforts and precious ally towards a musically interesting performance for the audience.

II. Questions and methods

Harpsichords and clavichords, after some eight decades of disinterest during the nineteenth century, have been built again in the last 120 years, following more and more closely the historical models: today historical keyboard instruments have gained again an important place in the modern musical praxis and their building is a well-established craft. Still they are referred to as *historical* instruments, in opposition to the *modern* ones, somewhat underlining the discontinuity in their history. What are the consequences of this interruption and why is it considered so important? As every craftsman can confirm, regardless of his actual field, when the living tradition of a specific handcraft gets discontinued, a lot of practical information about the building process simply gets lost. Because of this, it's impossible to resume simply from the last standpoint: reviving a handcraft only by looking at the final product, costs indeed a lot of time and efforts.² The more complicated and the less documented the historical process was, the harder to bring it up to live again and to get results which are close to the originals. It is thus easy to understand that, despite the fact that most of the harpsichords and clavichords built now are copies of ancient ones, many aspects of the way these were originally designed and made are still poorly understood or have not yet been researched.

Since every European nation developed its very own type of organ and since organ and stringed keyboard builders were the same persons more often than not, it is not surprising to find a similar variety among harpsichords and clavichords. Each country had in fact both its favorite stringed keyboard instrument and its own peculiar construction, often with several regional variants and sometimes with clear influences between countries. Differences could regard almost every

² A clear example of the research needed to revive a specific historical technique is the reconstruction of seventeenth century's metal casting, within the North German Baroque Organ Project in Göteborg, which was probably the biggest challenges of the whole project. Casting on sand was discontinued in Northern Europe in the last centuries, but evidences from surviving Baroque pipework clearly pointed out that this technique was relevant for a faithful reconstruction. Learning by trials and errors how to cast metal sheets on sand successfully was a long and expensive process, that would never have been sustainable for a commercial organ building company. On the other hand this process developed important knowledge and left us one of the finest organs of the last century.

aspect of the instrument: disposition and number of manuals for wing shaped harpsichords; fretting schemes and string-band orientation for clavichords; strings scaling and material, compass, overall geometry of the casework, materials and ways of construction for both type of instruments (including virginals and spinets). Just as on organs, these deep differences had of course also a major effect on the sound; since they were very consistent over several decades and within different dynasties of builders working in the same region, one should conclude that they were not just a product of individual idiosyncrasies and practical reasons; they were indeed connected to the acoustical ideal, or *Klangvorstellung*, the instruments had to fulfill and to their actual use in the musical praxis.

Among all parts that can influence the sound of stringed keyboard instruments it is commonly agreed that the soundboard plays the most important role. As Martin Skowronek shortly puts it: after fifty years of experience as builder, one has proof that a bad soundboard can make the most carefully made harpsichord sound ugly and in turn, a good soundboard can make an otherwise uninteresting instrument sound great.³ This is not at all a modern discovery: just to give an example, at the end of the seventeenth century, Johann Philipp Bendeler lists the soundboard in the first place among the common causes for harpsichords not to sound well.⁴ Around this part of the instrument a lot of more or less useful, bizarre, and “secret” tricks, have originated both in historical and modern times. Still, despite of the variety of practical methods, there is an unanimous consensus on the fact that the choice of the appropriate wood is crucial for the sound of the instrument. This is one of the basic assumptions of this work. This is our starting point: since different regional building traditions consistently employed different kinds of wood, they may have chosen one instead of another persuaded that it would have better met their *Klangvorstellung*. The scope of my work is to measure the difference that the soundboard material makes in the final sound. But far from being a merely technical work, since the sound is the purpose on which musical instruments are built, comparing the different sounds, especially in those cases where the divergence is bigger, will help us to understand which tonal characteristics were sought after and will give us a clue on which was the *Klangvorstellung* of the old masters.

Harpsichords and clavichords, as modest as they can appear from outside, are, when it comes to their acoustical behavior, a tremendously intricate system, made of lots of parts interacting in complex ways. String material, scaling, bridge shape, soundboard layout, thickness and barring, overall dimension of the instrument's chest and lots of big and small resonances that naturally and unavoidably take place in a musical instruments between its parts also affect the sound in a major way. Possibly even more than the material itself. So a big methodological question arises naturally: “How is it possible to compare the materials without having the results disturbed by these other factors?” Possibly this has never been accurately done before, because instruments built with different wood essences normally belong to completely different regional building traditions; this means that several main features differ. So in practice, to compare the sounds of a French harpsichord with a Venetian one, linking their acoustical differences only to the soundboard material, is as worthless as comparing the speed of a car and a moped only considering their respective weight: one could easily conclude that the heavier a vehicle is, the faster it would be.

The ideal situation would be to compare soundboards of different materials using the very same instrument. This is not really an option in a conventional instrument, as changing the soundboard has so many practical disadvantages, but I managed to invent and build a special kind of clavichord, with an interchangeable soundboard in which it is no longer necessary to remove strings to get the soundboard out and in. So eventually a more reliable comparison is made possible.

3 Martin Skowronek, *Cembalobau* (Frankfurt a. Main: Bochinsky, 2003), 104-5.

4 Johann Philipp Bendeler, *Organopoeia* (Frankfurt und Leipzig: Gottschick, 1690), 44.

III. Organization of the present work

From the beginning on, I planned to divide my project into several different parts. This is how the chapters of this work are structured:

-Introduction to wood: in order to understand the text completely, it is important that the reader has a background on how the material behaves and on which basic principles one should follow in woodworking. This chapter is kept simple on purpose and would be useful to read for every instrument owner and musician.

-Historical sources: before starting with practical experiments, it is necessary to determine, as accurately as the situation allows, which kinds of wood were used in which building tradition. Since a comprehensive study on soundboard materials has not yet been made, the first thing is to look at the historical literary sources dealing with instrument building; I will divide them up by country.

-Extant instruments: the second way to gain information on workshop practices is to consider the instruments still preserved in museums. I will discuss the problems I encountered, and sketch a tentative atlas of the wood used in European soundboards. I will also give general information on the four types of wood I was able to individuate.

-Experimental clavichord: I will describe with text, tables, pictures and a plan view, the special instrument I designed for my project. I will give information on its basic features, explain the reasons which stand behind its peculiar layout. I took care to allow the reader to follow the genesis and development of the ideas standing behind this invention.

-Measurements and recordings: in order to understand the behavior of different materials it is useful to compare their physical properties from a more scientific point of view. In this chapter I will first report the results of the tests I made on sample pieces before assembling them. I will also describe the recording process and show spectrum analysis graphs for soundboards of each material.

-Conclusions: in this last part I will evaluate the results of the previous chapters and compare them with the acoustical results. I will also report my personal impressions and preferences.

IV. Notes on the limits of this work

I feel I will be less than honest if I would not spend some words on the way the results of my project should be understood. As I explained, a keyboard musical instrument is a complex system of different parts interacting in an extremely complex way. Within this microcosm the soundboard material is still only one of the several parameters that can affect the sound, even if the old masters often seemed to have made efforts to secure for themselves what they thought to be the best wood. It should be clear that since the sound is a result of many interactions, the use of a certain wood alone, even if it may be important, is no guarantee of a certain sound, if other features of the instrument are not chosen according to the same principles.

Another risk is to link too tightly one single feature of the instrument to the compositional process in a sort of short-circuit conclusion, which again does not take into account many other aspects of the instruments and of the contemporary musical practice. For example, it would seem obvious to trace a direct connection between the use of a certain wood which imparts a fast decay with the rapid passages and chords of the late Renaissance *Toccatas*. Still, this does not take into consideration all other aspects of the instrument (which could work in the opposite way) nor does it explain why then, the very same pieces of music were also meant to be played on the organ, which

does certainly not lack sustain; it also fails to give accounts as to why similar passages are also found in music from other countries and for other families of instruments. Such kind of conjectures may very well be partly correct, useful and have some artistic relevance, but since they cannot be scientifically proven, I will not claim for them more objectivity than they deserve. Given the fluid situation of keyboard (and instrumental) music of early *epoques*, where the destination of one piece to the gentle clavichord or to the irreverent regal was more often than not just left to the player's taste, one should resist the temptation of tracing too strong conclusions based on soundboard materials.

On the other hand, with all these limits, it should be remarked here that anything that helps us to better understand the *Klangvorstellung* the old masters and their customers had for their instruments, gives us invaluable insights in the musical practice of the past and will guide us towards a more better taste as performers. Also for contemporary builders and restorers it will be interesting to measure the actual role of the material in the sound of one instrument. Moreover, the kind of instrument I designed can be used to test several other parameters as well: bridge shape and material, varnishing and surface treatment, thickness and soundboard tuning, different barring systems and so on. It was not possible to try out all of this for obvious practical reasons; but we hope that in the future somebody will or that we will at least have time to do it ourselves.

V. Acknowledgments

As for every human effort, nothing can be achieved or refined without somebody's help. This principle is more than valid for my work too: indeed almost everything I've written here, I learned from other people or books and even my most genuine ideas were stimulated by external suggestions. Indeed all human knowledge looks like a collective achievement and it should be shared as such. With this affirmation I don't want to compare my poor efforts to the highest accomplishments of human beings: all I'm pointing out is that all works follow the same rule and that nobody should be so selfish to claim he does not owe gratitude to anyone. I should indeed thank a lot of people, and I will try to mention at least the most important ones.

I thank in first place my parents and sister for having supported me in whatever I did during the last 30 years: it is clear that I won't be here without their help.

I would like to thank my kind advisor and professor Joel Speerstra for his support to my work and for all the useful information and suggestion he gave me not only during these two years, but since my first attempt to build a clavichord. I want to thank also my organ builder and friend, Andrea Zeni from the Val di Fiemme, who always provided me with the best wood he had in his workshop and advised on how to work it best. Without the technical and practical help of Carl-Johan Bergsten, the measurements part would never have been done: I appreciated his great kindness and curiosity. I would like to thank also professor Grant O'Brien for his kind hospitality in Edinburgh and advising: I will never meet another person with such an encyclopedic knowledge about historical instruments, who would still like to accompany me to Pubs.

It is clear that outside the GOArt's environment this work would have been much more difficult to carry out and I would like to thank all people working there. Munetaka Yokota gave me precious advice, feedback and allowed me to use his tools: his kindness was surpassed only by his curiosity about every aspect of instrument building. Hans and Ulrika Davidsson were also very supportive, especially during the first phase of the work: I thank them for giving me the opportunity to share my projects with their Danish students. Paul Peeters showed constant interest in my work and helped me with Dutch texts and in finding sources. Ibo Ortgies, during our frequent and interesting discussions about temperaments suggested me several interesting articles about instruments design. To everybody and to those whom I might have forgotten, a warm thanks!

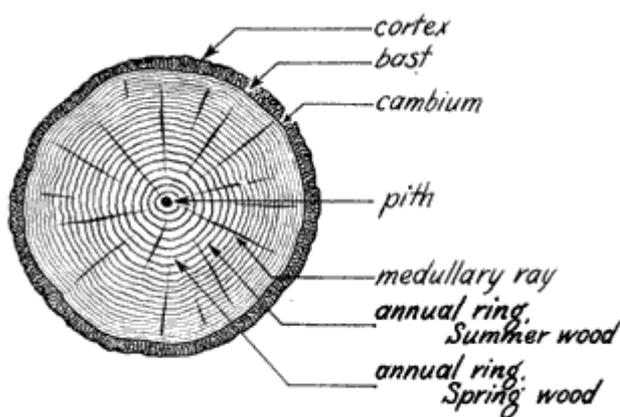
1. Preliminary discussion on wood as working material

In order for everybody to understand many of the indications about the wood used in soundboards, their preparation and descriptions of surviving instruments, a short introduction on the physical structure of wood and on basic woodworking practices has to be made. This will be useful both as source of information for those who never had any workshop experience and to make clear what I exactly mean with the terms I'll use in the next chapters.

Let's start with a brief and general definition of the term “wood”:

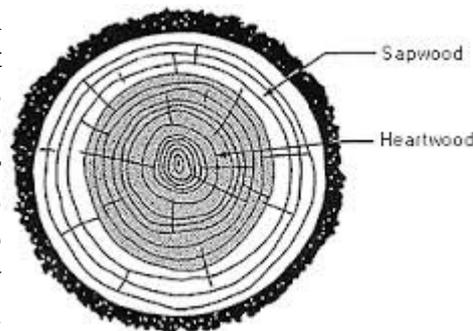
Wood is a porous and fibrous structural tissue found in the stems and roots of trees and other woody plants. It has been used for thousands of years for both fuel and as a construction material. It is an organic material, a natural composite of cellulose fibers (which are strong in tension) embedded in a matrix of lignin which resists compression. [...] In a living tree it performs a support function, enabling woody plants to grow large or to stand up by themselves. It also mediates the transfer of water and nutrients to the leaves and other growing tissues.⁵

Wood grows following both the biological development of the tree: young plants grow faster in order not to be shaded by older surrounding plants (so the first annular rings around the center are rather large) and the seasonal rhythm: starting from the center, or pith, each year a new **annular ring** is grown. It is important to note that the growth is affected by the climatic conditions to such an extent that scientists can actually “read” the annular rings of a tree to gain information on the climates of a particular period: arid, rainy or windy years as well as uncommon events like fires are “registered” by the trees in form of oddly shaped rings.



But even in absence of exceptional conditions the natural seasonal course is clearly distinguishable: at the beginning of the good season, in spring, a new annular ring is started and grows rapidly; this portion is called **springwood** (or earlywood) and is normally lighter in color and softer than the later part of the annular ring, called **summerwood** (or latewood). In coniferous trees used in soundboards this difference is usually very marked. In autumn and winter trees are biologically at rest and no rings are grown.

Some species also show a more or less marked differentiation between **heartwood** and **sapwood**: the first represents the central, elder part of the trunk, in which cells are already dead and has primarily a supporting function. The latter is made up by the most external and recent annular rings and has a more active part in the tree life. The difference is not just in their function: heartwood has undergone chemical transformation that made it darker, statically stronger and less likely to suffer damage from insects and atmospheric agents. In coniferous trees it is usually rich in rosin, which contributes to make it aromatic and more resistant to external agents.



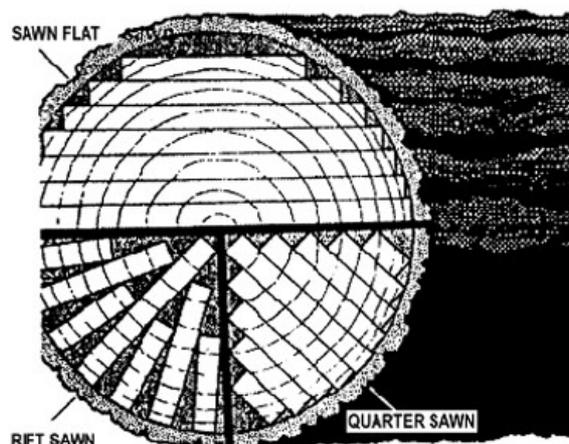
⁵ <http://en.wikipedia.org/wiki/Wood> Even if one should not always trust Wikipedia as source of informations on very specific subjects, I regard its definition of wood more than suitable for this general introduction.

These characteristics are indeed important when it comes to woodworking: for hard-wearing and durable parts, choosing heartwood makes indeed a difference, but as I said, not all species present this differentiation. Speaking of the most common in instrument building: Cypress, Pine, as well as Oak and Walnut, present a more or less clear (it varies from tree to tree) delimitation between heartwood and sapwood. Spruce and Fir, as well as Lime, Beech and Maple do not show such a marked differentiation.

Another distinction often heard is that between **softwoods** and **hardwoods**, which has nothing to do with different areas of the trunk, but simply refers to wood coming respectively from conifers (gymnosperms) and deciduous species (angiosperms). Indeed such labeling is a bit arbitrary, as not all softwoods are “soft” and not all hardwoods are really “hard”. What is important to keep in mind is that wood from conifers and other trees have obvious differences in their micro-structure, appearance, smell and properties.

Before wood can be used it must be sawn into planks. The way they are oriented in relation to the circumference of the tree, due to the presence of annular rings, also makes a huge difference in their characteristics. This was widely known and understood early in historical times, since improper use of the wood easily leads to cracking and warping.

Sawing planks parallel to the tangent of the trunk (tangential-sawn, flat-sawn, most commonly referred to as **plank-sawn**) is the easiest and makes the most of the volume of the trunk. Annular rings combined with this sawing direction originates in planks a nice and decorative flame-like texture.



By sawing planks roughly following the radius of the trunk (radial sawn, mostly referred to as **quarter-sawn**), one gets annular rings which stand roughly perpendicular to the width of the board and creates a more regular striped pattern. In this way, however, there is a bigger proportion of wasted material and the plank width is also limited.

To understand what actually happens when sawing wood in one or another way, one has to consider how it shrinks or swells differently in different directions as moisture changes: when a tree is felled, wood starts immediately to dry out until the point when it reaches equilibrium with the moisture present in the surrounding air. Fresh wood is not yet suitable for use and drying it out is necessary: this process is called **seasoning**. The original tree moisture content⁶ varies greatly from species to species and from tree to tree, but in general from the felling point to approximately a moisture content of about 28%⁷ the loss of water does not yet imply any shrinkage. After that point and until the wood has not reached an equilibrium with the air moisture, **shrinking** takes place. Should moisture in the air increase after planks have dried, **swelling** occurs.

6 Moisture content is calculated as percentage of actual weight minus oven dry weight, all divided by the oven dry weight. For example here there are typical values for 1 mc of fresh and oven dry Spruce: $(860 - 450) / 450 = 0,91$. It means that this wood in its fresh status has a moisture content which is the 91% of its oven dry weight.

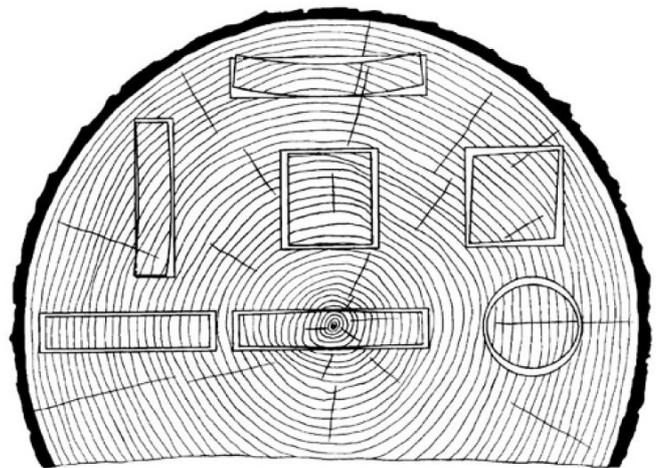
7 As wood is a natural material and varies between species, as well as between trees of the same species, all of this value are approximations, that only have the purpose to make the reader understand the overall drying process.

It is worth noting that since air moisture is a parameter depending on continuously changing atmospheric factors, this process of shrinking and swelling actually never comes to an end: it is indeed a built-in characteristic of wood and woodworkers have to deal with it all the time; failing to take this into consideration ends up in **warping** and **cracking** as soon as the weather changes after an artifact has been assembled.

Seasoning is a delicate process: the loss of humidity must be gradual and equal in the whole piece. Shrinkage tensions are huge, actually much stronger than the material itself; this in turn means that if the seasoning is badly done, and different part shrink at different speeds, terrible cracking will take place, making even the best wood good only for the fireplace. This is also why sawing has to happen before the trunk is dry.

Historically, wood drying took place naturally by simply exposing it to the air and stapling planks in a way that ensured constant air flowing, while avoiding rain and direct sunlight as much as possible. The process was very gradual and slow (which is good) but it took several months or even years for the thickest planks to fully dry out (which made the return of invested capital also slow). Modern techniques involve kilning (i.e. artificial drying in an oven) and reduce the time to few days, while a mix of the two methods is also often used. Still none of the two methods is good enough for our purpose, as the typical moisture content of the commercial planks is around 12-15%, which is fine for carpentry and general joinery, but slightly too high for delicate joinery and musical instruments. So it is generally useful to leave raw planks to season for a longer time in the workshop; the best is to resaw soundboard planks to roughly the final thickness using a bandsaw⁸ and then let them rest in a warm dry place indoors, like a heater. Generally speaking, on harpsichords and clavichords the thicknesses used are so small that they ensure a rapid moisture stabilization in this way; yet it does no harm to leave them to dry for a longer time.

The other point that is vital to keep in mind doing woodworking is that the percentages of shrinkage and swelling varies greatly in different directions: the minimum is registered along the grain direction and is typically 0,1-0,3%; across the grain, a shrinkage of about 5-10% in the tangential direction and of about 2 to 6% in the radial direction can be expected. This means that a quarter-sawn board tends to move just about half as much as plank-sawn one, but these differences in shrinkage also cause more or less evident deformations of the planks (warping) and also different disposition to cracking. Thicker boards are more affected than thin ones.



Speaking of instrument building and soundboards in particular, this easily explains why quarter-sawn wood is so sought after:⁹ considering a typical ca. 75 cm wide, quarter sawn,

8 Many joiners nowadays does not use bandsaws very much, as they are not as fast and clean as other machines. Yet they are the only useful machines, when it comes to very deep vertical cuts (100+ mm). They are also quieter, safer, less power-consuming and they waste less material.

9 The only notable exception to quarter-sawn soundboards, are the old Renaissance Italian one made of Cypress. It may seem risky to use such planks, as one may expect important deformations. Still those extremely old harpsichord have survived in excellent conditions, often better than newer ones. This may be partly due to a thorough drying process before installation and partly due to the fact that Cypress is a very dimensionally stable wood.

Nowadays Unfortunately quarter-sawn wood is normally not available in sawmills as it used to be in historical

harpsichord soundboard, an average shrinkage of 4% would mean a maximum dimensional variation of about 3cm (which would already produce a disaster); on a flat-sawn, the shrinkage would be almost twice as much! These extreme values, however, refer to fresh boards as a starting point and to completely dry ones as a result. In normal conditions, air moisture seldom gets below 30% or above 80%, which is the range where less movement take place in the planks; and of course on the other side soundboards aren't made of fresh wood. So the actual shrinkage one can expect is less than that.

The problem of dimensional stability is, however, never radically removed and can only be decreased: sources and modern instruments builders agree that much care has to be taken in choosing stable and well seasoned wood, in gluing the ribs, the bridge and the soundboard itself to the frame. The results of excessive dryness typically are a sinking soundboard (which is not favorable to the sound) and especially cracks, while there is much more tolerance on the “wet” side: the soundboard just starts to rise, arching itself; except in the case of really extreme humid weather, all that can happen is that the instrument goes out of tune.

This explanation makes immediately clear that the best conditions for installing a new soundboard are the driest ones a builder can expect the instrument to be exposed to, because once it is glued on the frame, if it shrinks, the wood will unavoidably crack.¹⁰ So it is clear that well-seasoned planks, quarter-sawn wood, appropriate barring, and gluing in dry conditions are the keys to a durable instrument. On the other hand, not even the best instrument builder can make miracles happen: wood will never stop working after the instrument has left the workshop and so the owner is in charge of making sure that the instrument does not come in contact with extreme humidity conditions, keeping it away from heating, direct sunlight and humidifying (or drying) the room if necessary.¹¹ If it seems to be asking too much to care for an instrument, everybody should keep in mind that extreme moisture or dryness are not good for human health either.

From this introduction it should be clear that, generally speaking, good soundboard wood should meet this basic, partly obvious, criteria:

- being **knot-free**, as knots are fairly dense, acoustically dead and also fall off easily
- having no **cracks**; these are signal of bad seasoning or intrinsic tendency to split
- being well **dry**, for the reasons discussed above
- being **quarter-sawn**, or close to, for better a better stability
- having rather **regularly spaced annular rings**, which leads to an even density
- having **straight grain**, as irregular grain affects flexibility and is often difficult to plane
- being fairly **close-grained**, as softwoods with too wide annular rings tend to be weak

These criteria, however, are only valid as general rules: old masters could build fine soundboards even using wood of rather modest quality if they had to; several surviving instruments can prove this. On the other hand nowadays, it is reasonably simple to get good quality material, which is usually easy to work with and does not make out much of the instrument price. The question therefore is whether it is convenient, on a newly made instrument, to cope with all the disadvantages that poor quality wood involves.

times. One instrument builder, except from buying from specialized soundboard wood suppliers, is left with only two options: buying a whole trunk and let it saw according to his own directions; or gently ask the sawmill owners for permission to search for the middle planks of the trunk. Since this typically takes long time, as one has to move a lot of planks and since choosing one's own wood is getting less and less common, it's not always so easy.

10 It is a good thing to avoid cracking for several reasons. This does not mean, however, that a cracked soundboard needs necessarily to be replaced or fixed: small cracks, unless they are too many do not affect the sound much.

11 It is very useful to have an hygrometer next to the instrument. Such a device costs nowadays only about a dozen Euros, but it helps avoiding damages of several thousands.

2. Written sources on wood employed in soundboards

Little has been written on soundboard materials for harpsichords and clavichords in modern times. Typically, one finds a couple of sentences scattered in several different articles or books. A comprehensive study on this particular topic has not yet been made. The only books that are worth mentioning are Hubbard's pioneer work *Three Centuries of Harpsichord Making*,¹² and Klaus's *Besaitete Tasteninstrumente*:¹³ both containing chapters dedicated to the soundboard's construction and material of keyboard instruments; they also collect some short quotations from historical sources. Since, however, the soundboard material is no more than a side aspect in the frame of such encyclopedic works, they don't offer larger comments on sources and do not provide a sufficiently defined picture of the various regional building schools. Despite the great merit of his work, Hubbard's approach to our question appears today rather naive. Not mainly because of some imprecise translations, but because of his attempts to identify "the" most favored type of wood by analyzing mixed sources from different countries.

So at the moment of writing, in order to gain information on the use of wood in historical keyboards, since direct verbal exchange with the old masters about their practical choices is no longer an option, we are left with only two main possible ways:

- referring to contemporary **written sources** dealing with instrument building
- looking at the **surviving instruments**

Unfortunately, both options have a number of limitations, and it is worth analyzing them openly before starting the discussion.

2.1 On the limitations of written sources

Nearly all of the written sources come from people who did not build instruments themselves: in fact most treatises are from theorists or musicians, whereas people like Pisarenis, Ruckers or Silbermann never wrote one. Thus one should question in which kind of relationship did writers stand with the actual makers and their workshop practices. There is in fact a long tradition of antithesis between theory and practice in the European culture, which can be traced back at least to Plato's times: on one side the philosopher, who only works with his intellect and truly understands universe's laws; on the other side the humble technician, who merely works with his hands and only has a limited grasp of the essence of things. This tradition also survived in the Christian middle ages and later, especially in countries like Italy, where the classic heritage was stronger. In the musical field, during the middle ages and long after, there has been an opposition between music theorists and musicians also, where the *musicus theoreticus* was seen as the real musician who knows the principles of the musical science and the *musicus practicus* was merely regarded as someone skilled in playing.¹⁴ In this view the instrument builder was yet one step down in the ranking and had a rather humble status.¹⁵ So whenever theorists wrote, we must not forget that they were not really so interested in reporting too deeply about practical issues: that was simply not what they were supposed to do.

12 Frank Hubbard, *Three Centuries of Harpsichord Making* (Cambridge: Harvard University Press, 1965), 201-4.

13 Sabine Klaus, *Besaitete Tasteninstrumente* (Tutzing: H. Schneider, 1997), 77-96.

14 This easily explains why Italian Renaissance treatises are so full of interest towards tuning, temperaments and monochord divisions.

15 This was a constant over the whole period examined and is still partly true. When one reads builders' biographies one also encounters financial problems more often than wealth; today is still difficult to make a living as instrument builder. Considering all the technical and practical knowledge that instrument making involves, is probably one of the worst paid job.

On the other hand we must imagine that instrument builders were a rather “reserved” folk. It is especially important to keep in mind that arts and trades until the late eighteenth century were organized within the traditional guild-system, where the esoteric tendency to keep practical knowledge within the workshop was strongly present. We tend to think nowadays that instrument builders did not write treatises only because they were illiterate. It may be partly so; still one must assume that if builders did not give detailed instructions on how to build organs, harpsichords or clavichords, is also because they did not want other people to be able to do that.¹⁶ Diderot, under the article “ENCYCLOPÉDIE” of his monumental work, writing about the efforts made by the Encyclopedists to gain knowledge about handcrafts, puts it in this terms:¹⁷

Il y a des circonstances où les Artistes sont tellement impénétrables, que le moyen le plus court, ce seroit d'entrer soi - même en apprentissage, ou d'y mettre quelqu'un de confiance.

Apparently, in his times, the easiest way to get information on crafts was to have an apprenticeship with some of the masters. Costanzo Antegnati, who was a famous organist, composer, and organ builder, is a good example of how separation between workshop praxis and writings was the norm. In 1608 he published a small treatise called “*L'Arte Organica*”, where he highly praises the art of organ building, giving a brief account of his family's tradition and an index of organs made by him and his predecessors.¹⁸ Despite the fact that he was surely best informed on his own building activity, he did not bother to go into any construction details and provides us only with registration indications and tuning instructions, which is precisely what the final user, the musician, was expected to know about organs. The famous organological descriptions by Praetorius¹⁹ or Kircher²⁰, for example, are interested in giving details about the appearance, dimensions or compass of instruments and of course they discuss the erudite problem of musical temperament; still if we search more deeply for technical building details, we find almost none. The famous treaties by Barcotto²¹ and Werckmeister,²² who are meant to instruct organists on organ building, also follow this rule: no one gives enough practical details to start working. Both texts are indeed mostly focused on instructing organists on how to distinguish a good organ from a bad one. Werckmeister in his preface even makes clear that he does not expect to make any friends among organ builders by publishing his book; he goes on justifying himself that the only purpose of going into construction details was to prevent poor countryside parishes from being cheated by the less honest craftsmen. The organ world generally reflects that of stringed keyboard instruments, but since costs and commissioners were completely different, we must admit that much less effort has been spent explaining the construction of the latter ones.

It is thus not surprising that sources dealing with our particular topic, the soundboard material, are generally scarce and neither cover the whole period questioned nor every regional building tradition. Those we have are rather late (written mostly after 1750, in a period where the traditional guild system was probably already evolving) and originated in countries where the influence of the Enlightenment was greater.

16 David Tannenberg's instruction and drawing for building clavichords are an exception to this rule: since there was a high demand for keyboard instruments among immigrants in the new world and Tannenberg was completely busy building organs, he did not mind to give practical instruction on how to build a clavichord, since he would never have come to do it himself. Cf. Thomas McGeary, “David Tannenberg and the Clavichord in Eighteenth-Century America.” *Organ Yearbook* 13 (1982), 94-106.

17 Denis Diderot, Jean-Baptiste Le Rond D'alembert et al., *Encyclopédie ou Dictionnaire raisonné des sciences* (Paris, 1751-1772). Since nowadays several digital editions of this famous work are available, I will provide in the bibliography the URL to one of them, since it is unlikely that anyone will consult the original. The *Encyclopédie*, as every modern dictionary, is organized in entries, so I'll not give page indication, that would only work with the printed edition, but the name of the correspondent entry.

18 Costanzo Antegnati, *L'Arte Organica* (Brescia, 1608).

19 Michael Praetorius, *Syntagma Musicum* Vol 2: *De Organographia* (Wolfenbüttel, 1619).

20 Athanasius Kircher, *Musurgia Universalis* (Roma, 1650).

21 Antonio Barcotto, *Regola e breve raccordo* (Padova 1652).

22 Andreas Werckmeister, *Erweiterte Und verbesserte Orgel-Probe* (Quedlinburg, 1698).

2.2 Representative sources divided by country

-England

Not very much has been written in historical times on harpsichord making in England. Actually, it seems that the harpsichord maker's craft itself was established there somewhat later than elsewhere. Many of the earliest builders were immigrants from the Low Countries. Moreover, the number of instruments preserved dating before 1700 is rather small and they show Italian or Dutch influences. Since there is a substantial keyboard repertoire dating from these early times, the question of which kind of instruments the famous *English virginalists* were actually playing, arises. It is indeed hard to tell, but the possibility that instruments were imported is not unlikely. For example, one of the oldest instruments preserved in the Victoria and Albert Museum is the lavishly decorated "Queen Elisabeth's Virginal": it was made in Venice by Giovanni Baffo around 1570 and was owned by the Queen herself at the end of the sixteenth century. Rather than representing an exception, many more instruments were probably imported from Venice, which was the major center of instrument making during the late Renaissance. After that, others began to be imported from Holland, when the Flemish school reached its peak. Finally, starting from the end of the seventeenth century, a significant output of plucked instruments (bentside spinets and harpsichords) can be linked to the city of London and show a distinctive English character.²³

It is thus not surprising that the only English source I was able to find on this topic, which dates back to the times where the genuine English school was starting, describes instruments made out of wood that is not found in England. The author, **James Talbot**, who was professor of Hebrew at Cambridge, compiled a manuscript²⁴ with measurements and descriptions of several different musical instruments. He was himself not an instrument builder and it is not clear whether he collected information on instruments in order to write a book or for other purposes. Anyway, in their present form they are just short notes written around sketches of the instruments:

Barrs usually of Firr never less than 4 never more than 7 [?]. If not let into - - then a piece of Cloth is glued to belly over Barr. [...]

Belly best of Firr, sometimes Cedar or Cypress. Best Firr fine grain rare in England

These brief indications allow us to make some considerations. First, there is no extant English soundboard made out of Cypress or Cedar. So even if the possibility that some early English maker may have been importing exotic wood cannot be completely discarded, it seems more likely that Talbot is simply talking about imported Italian instruments, that may still have been common in his time. Second, his preference is clear: the best wood is fir and he adds that the best, fine-grained quality was rare to find in England. This in turn raises the question of where the local maker got their wood from, which is hard to answer. Still his indications on the most suitable wood are clear.

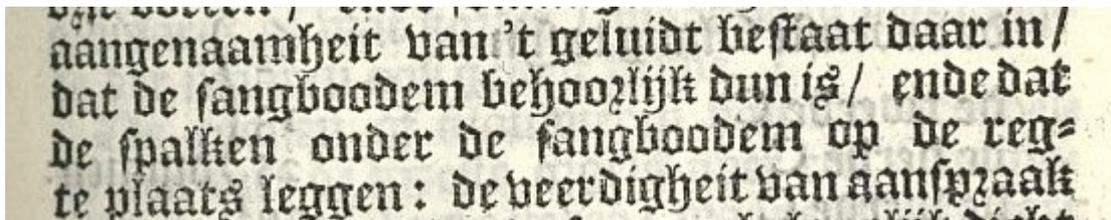
23 The Great Fire of London, which dates from 1666 may also have played a part in destroying earlier instruments. But it must be reminded that in the seventeenth century the city still had a rather modest size.

24 Christ Church Music MS 1187, Oxford. The text, which was compiled between 1685 and 1701 was never published. It is fully reproduced in Appendix A of Hubbard, *Harpsichord Making*, 3.

-Low Countries

While Venetian makers dominated in the sixteenth century, Flanders and especially the city of Antwerp, were the most important center of keyboard instrument building worldwide in the seventeenth century. The Ruckers dynasty is deeply connected to this flourishing era, as their instruments were exported and appreciated through all of Europe. Their sound aesthetic and construction principles deeply influenced later building traditions (especially the French) and their harpsichords were highly esteemed and sought-after practically until the beginning of the piano-era. The decline of their business is mostly connected with political changes: in 1648 the Treaty of Münster, which granted independence to the Dutch United Provinces, forbade navigation on Antwerp's most important waterway, destroying the city's economy.

One of the most important sources on instrument building of the end of the seventeenth century is **Claas Douwes'** treaty *Grondig Ondersoek van de Toonen der Musijk*.²⁵ Douwes seems to be very well informed on instrument building and it is likely he was doing some building himself²⁶. He gives us indeed many useful details, especially about stringing patterns of contemporary harpsichords and clavichords and testifies to the use of proportions as useful approximations for meantone intervals in fretted instruments, which is particularly important for the layout of fretted clavichords.²⁷ He states that the compound of correct soundboard thickness and ribbing is the key to a pleasant sound.²⁸



Douwes, however, does not go into further details about soundboards and he does not give any indication of which wood one should employ.

An anonymous treaty, titled *Verhandeling over de muziek*, gives us, as usual for eighteenth century treatises, a more deep insight in the construction of the various parts of a harpsichord. It is indeed an important source, because it's one of the few describing very practical matters such as how to curve a bentside or make jacks.²⁹ The author is also clear about the wood suitable for soundboards and gives concrete thickness indications ($\frac{1}{4}$ of an inch and even thinner in the treble):

De Zangbodem wordt vervaerdigt van eene soort van vuurenhout, dat uit Zwitserlant koomt, en onder den naem van zangbodemenhout is bekend [...]

[...] alles wel droog zynde schaeft men den zangbodem tot op iets minder dan $\frac{1}{4}$ d., en by de korte snaeren noch wat dunner, [...]³⁰

25 Claas Douwes, *Grondig Ondersoek van de Toonen der Musijk* (Franeker, 1699).

26 Douwes claims to have invented a special kind of Pedal clavichord.

27 I did not have a chance to read this text before constructing my experimental clavichord, but I spontaneously found useful to use this kind of proportions. In such a way one can escape difficult calculations, work in a simple geometrical way and still be very precise. I used the proportion of 23 to 24 (0,958) for the chromatic semitones (0,957) of my $\frac{1}{4}$ meantone instruments because it's practical and involves a discrepancy of only about 1mm on a 1 meter long string. I discovered afterwards that this is exactly the value Douwes gives. For my eighteenth century style, $\frac{1}{6}$ comma meantone instruments I regularly use the ratio of 19 to 20 (0,9500), which is stunningly congruent with the chromatic semitone of this temperament (0,9501).

28 Douwes, *Grondig Ondersoek*, 105.

29 Anon., *Verhandeling over de muziek*, 's-Gravenhage (den Haag) 1772

30 Anon, *Verhandeling*, 200-201.

“Vuren” is still today the Dutch word to indicate Spruce. The tree itself is called *Fijnspar* and since “spar” is used also to designate Firs as well, it could generate ambiguities; but fortunately the anonymous author used the term *Vuurenhout* about which there is no such confusion. Interestingly this text is the only historical source known to me that recommends varnishing harpsichords' soundboard (on top and underside), both as protection and for improving the sound.

Verhandeling over de muziek attests that wood used in Low Countries was imported from Switzerland and how that historically happened is very well worth a mention: until very recent times lumber was mainly transported on water, as carrying them on wagons would have been expensive, tough and not really faster. As most trunks already float by themselves, it was not necessary to load them on a ship, but they were rather tied together forming enormous rafts and these were governed either by big ships (especially on open sea or big rivers), by horses or just by men traveling on them (in case the river's stream was strong enough to ensure them to move). Such a transporting system was already used in the Mediterranean Sea at the times of King Solomon around 1000 B.C. and in more recent times was used to build up Venice and supply the city with the huge amount of wood it demanded: wood came there mainly from the northern part of Veneto and the southern parts of Tirol.³¹



In German countries this system was called *Flößerei* and their workers *Trifter*:³² it's first mentioned by Gaius Julius Caesar, who described the Helvetii transporting trunks precisely over the Rhein. As we can see in this picturesque, early seventeenth century illustration depicting *Trifters* from the Oberrhein, the *Flößerei* was already well organized in the Ruckers' time: rafts were made in several well organized layers and heavier trunks like oak, were mixed with lighter conifers, as they were too heavy to float themselves. The trip from Switzerland to the Netherlands over the Rhein took several days: during this period logs were almost completely soaked in water: this partly washed them from minerals and organic substances and also made their wood somewhat easier to season and less subject to warping. This ancient and clever method of transporting flourished until loading trunks on the railway became economically competitive and was eventually discontinued almost everywhere in Europe between the second part of the nineteenth century and the Second World War.

31 It is worth noting that Venetian harpsichord masters could get the best spruce from the Alps very easily, but apparently they were not interested in using it for the main parts of their instruments excepting bottom, liners and soundboard ribs, where its extremely favorable stiffness to weight ratio may have been crucial.

32 *Trifters* generally had a low social status; their work was physically very tough and their life expectancy tended to be low as was their salary.

-France

Although very few early instruments have survived, there seems to be a consensus about the fact that France had an earlier indigenous harpsichord building tradition that at some point became so influenced by the Ruckers' success, that later French instruments depart little from Flemish standards, especially regarding soundboards. I was able to find some French sources, two from the beginning of the seventeenth century, the other from the middle of the eighteenth and they seem to reflect these two different stages.

Father **Marin Mersenne** (1588-1648) was an important French theologian, philosopher, mathematician and music theorist. He was in contact with many of the prominent European scholars of his time, like Descartes, Pascal, Galileo and Huygens. He was also a friend of the famous organist of Rouen, Jean Titelouze, who gave him advice, while working on his monumental musical treaty called *Harmonie universelle*.³³ In the second volume of the second part of this work, we find a description of stringed keyboard instruments. About the soundboards he writes:³⁴

Quant à la table, elle doit estre de bois refineux, comme de cyprez ou de cedre, & principalement de sapin, qui est le plus estimé de tous les bois pour cet vsage. Son espaisseur est d'une ligne ou environ, & quand elle est bien collee & appuyee sur les tringles ou sommiers, c'est elle proprement qui compose l'instrument, car si l'on tend des cordes sur vne table de sapin de cette espaisseur, elle rend du son, encore qu'il n'y ait derriere ou dessus nulle boëte, nul coffre, ou corps d'instrumens, le reste ne seruant quasi que pour la tenir en estat, afin qu'elle puisse supporter la tension des cordes.

Here Mersenne states that the soundboard has to be of refined wood like: Cypress, Cedar and “sapin”, the latter being regarded as the best one. The board has to be about one line (*ligne*) thick or so, which corresponds to 2,25 mm, and he explains that this part of the instrument is the most important for the sound. His indications on wood seem to reflect a much less standardized situation than we see in the eighteenth century instruments. We must, however, admit that not one of the surviving French instruments has a Cypress or Cedar soundboard and that Mersenne might have seen such instruments abroad, since he traveled several times to Italy and Holland. Moreover Italian builders until Mersenne's time held a sizable part of the market and exported everywhere, so he might have referred to imported instruments, while writing about the use of cypress. Still for example the harpsichord made in 1537 in Leipzig by Hans Müller also shows a Cypress soundboard: we are thus not entitled to completely exclude the possibility that early French instruments may have had Cedar or Cypress soundboards as well.

Not directly related to the material, but also relevant for the sound quality, here there is a passage, where Mersenne explains his opinion about one of the most crucial aspects of instrument building:³⁵

Manichordion il est au milieu. Or quant à la bonté de l'Épinette, elle depend de plusieurs conditions & particularitez, mais particulièrement des barres qu'on met deffouz la table, d'autant qu'il est difficile de barrer parfaitement les Epinettes, & est l'un des plus grands secrets de l'art, dont ie laisse la recherche aux Facteurs.

33 Marin Mersenne, *Harmonie Universelle* (Paris, 1636).

34 Mersenne, *Harmonie*, 2.

35 Mersenne, *Harmonie*, 7.

Mersenne states that the quality of a Spinet mainly depends on barring. Placing bars is, however, one of the most important secrets of the craft. As we can see, even if Mersenne is possibly the most practically-oriented theorist of his times, he is aware of craftsmen secrets and does not go deeper into details.

Mersenne and his works were very famous in their time, so when **Pierre Trichet** started to work on his *Traité des instruments de musique* around 1640, he began to contact Mersenne on several organological matters.³⁶ This work was never published and remains as a manuscript. Indeed the impression is that Trichet's work borrows most of its information from Mersenne. Describing the *Espinette* he states that it's "upper table should be of very thin *sapin* rather than any other kind of wood".³⁷ *Sapin* is exactly Mersenne's favorite wood, but Cypress and Cedar disappear in Trichet's text.

The first edition of the famous *Encyclopédie* was published in Paris from 1750 to 1765 and represents the efforts of a large team of scholars around Diderot and d'Alembert.³⁸ The text, meant to be a *summa* of human knowledge, clearly embodies the new ideals of the Enlightenment Era and a new disposition towards art and crafts: the Encyclopedists, in open contrast both with the classical figure of the *philosopher* and the medieval guild mentality, tried to document as faithfully as possible the actual workshop practices. The entry "CLAVECIN" is contained in the third published volume of 1753, and gives an interesting description of how to prepare a soundboard and glue bars:

On fait ensuite la table qui doit être de sapin de Hollande, sans nœuds, ni gersures, que l'on refend à l'épaisseur de deux lignes ou environ, on dresse bien chaque planche sur le champ & sur le plat qui ne doit pas avoir plus d'un demi-pié de large, parce qu'une table composée de pieces larges, est plus sujette à se tourmenter & à gauchir : on observera de n'assembler les pieces qui doivent composer la table, que long-tems après qu'elles auront été débitées, & de choisir le meilleur & le plus vieux bois qu'on pourra trouver ; d'autant plus qu'après la bonne disposition de tout l'ouvrage, c'est de la bonté de la table que dépend celle de l'instrument. [...]

Lorsque la table est entierement collée, on l'applique sur un établi bien uni & bien dressé, l'endroit ou le dessus tourné en-dessous ; on rabotte ce côté, on le racle avec un racloir (outil d'ébéniste) ; on retourne ensuite la table de l'autre côté, on y fait la même opération, & on la réduit à une ligne au plus d'épaisseur.

Lorsque la table est achevée, on la barre par-dessous avec de petites tringles de sapin *a, b, c, d, e, f, fig. 3.* posées de champ : ces tringles n'ont qu'une ligne & demie ou deux lignes d'assiette, sur environ un demi-pouce de haut ; elles sont applaties par leurs extrémités. A ces tringles en communiquent d'autres encore plus menues, 1, 2, 3, 4, &c. aucune de ces tringles, soit grandes, soit petites, ne doit être mise ni en long, selon le fil du bois, ni même exactement en travers ; le moins qu'on en peut employer est toujours le meilleur ; il suffit qu'il y en ait assez pour empêcher la table de voiler, & pour servir de lien aux pieces qui la composent.

The author states that the soundboard is made of planks without knots, roughly two lines thick (4,5 mm). Individual pieces forming the board must not exceed a half-foot width, as wider pieces are more subject to warping. One has to choose the best and oldest wood he can get, as from the soundboard depends the quality of the instrument. Once pieces are glued together, the board has to be planed to a thickness of one line (2,25 mm). The bars, which should be triangular in shape should be as few as necessary: they need to tie the board's pieces, but they don't have to inhibit its movement.

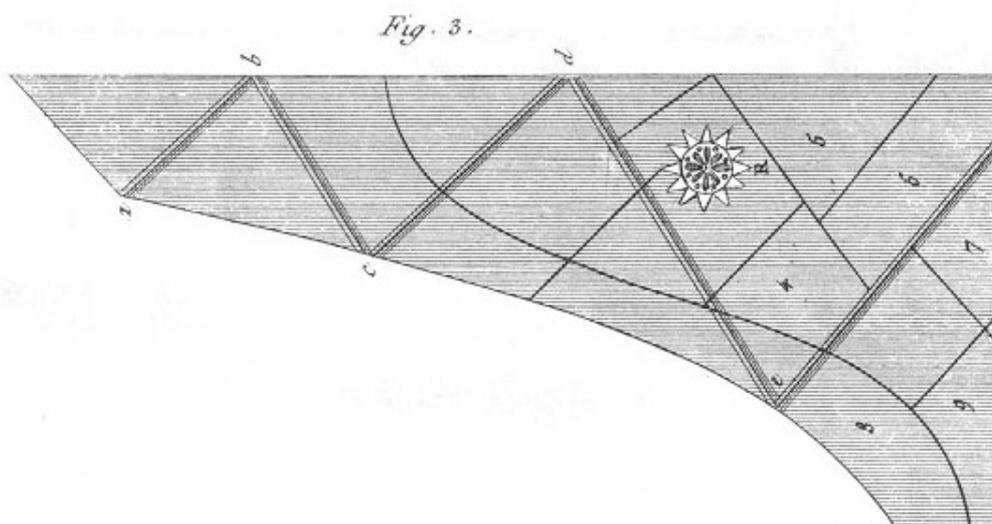
36 Bibliothèque interuniversitaire Sainte-Barbe, Paris: Ms 1070. It was not possible for me to have access to the manuscript nor to look at modern editions of the full text. The entries on plucked keyboard instruments are reproduced (in translation) in Appendix I of Hubbard, *Harpsichord Making*.

37 Hubbard, *Harpsichord Making*, 340.

38 Diderot et al., *Encyclopédie*.

It is remarkable that the thickness indications of the *Encyclopédie* perfectly match those of Mersenne, but in this case the wood indicated is only one: *sapin*. Indeed a certain kind of standardization since the early seventeenth century had taken place and the Ruckers' style of soundboards had become predominant. The mentioned country of origin is Holland but, as Frank Hubbard noticed, since we already know that Dutch wood suppliers got their logs (especially soundboard wood) directly from Switzerland over the Rhein's *Flößerei*, we can infer that French soundboards were also possibly of Swiss origin.³⁹

The barring style suggested by picture in the *Encyclopédie*, however, does not look Flemish at all, nor does match the remark of keeping it as simple as necessary. Such a disposition, indeed, isn't found on any historical instrument I know of and seems to be rather strange. It would probably be acoustically unsatisfying because of the big bars crossing the main bridge at several points, which are likely to create many stiff and acoustically “dead” points. I wonder if such an arrangement was really used on actual instruments.



The main question, however, is that of identifying the wood to be used. Mersenne begins indicating “cyprez”, which certainly stands for Mediterranean Cypress (*Cupressus Sempervirens*) and “cedre”, which may stand both for Lebanon Cedar (*Cedrus Libani*), a wood known from antiquity, or possibly for one of the many Cedar-like woods from the new world, which were regularly imported and widely used in Spain in Mersenne's time. Anyway, since no European instrument known to me survived with a Cedar soundboard, I will not go further into the matter of which trees could actually be meant under the name “cedre”.

It is remarkable, however, that Mersenne, Trichet and the *Encyclopédie* all give a clear preference for *sapin*. According to modern terminology, it should indicate Fir (*Abies Alba*), which, however, sounds rather unexpected to me, since many French harpsichords I found in museum catalogs, as well as their Flemish models, had a soundboard made of Spruce (*Picea Abies*), *épicéa* in French. So I decided to start looking for an explanation directly in the *Encyclopédie* itself. There is no entry at all for “EPICEA”, but a very long one for “SAPIN”, which is primarily devoted to Firs. Under this tree, however, the text also lists some European and American varieties of Spruce, probably reflecting the fact that in those days they were thought to belong together.⁴⁰ The number 1 and 6 of this list are particularly interesting, because they refer to the two mentioned trees, one indicated as “true sapin”, the other often as “épicéa”, but still regarded as the most common European *sapin*:

39 Hubbard, *Harpsichord Making*, 204.

40 Modern botanists classify *Picea* and *Abies* (Spruce and Firs) as two independent genera of the family *Pinaceae*.

1. Le vrai sapin ou le sapin à feuille d'if, ou le sapin blanc ; c'est à cette espece qu'il faut particulièrement appliquer ce qui a été dit ci-dessus. Il veut un meilleur terrain que l'épicea, il faut plus de soins pour l'élever & le transplanter, & les graines tombent dès le mois d'Octobre avec les écailles qui composent le cône ; ensorte que si l'on veut avoir des cônes entiers pour conserver la graine & l'envoyer au loin, il faut les faire cueillir bien à tems. Son accroissement n'est pas si prompt que celui de l'épicea ; il n'est ni si vivace, ni si agreste, mais il a plus de beauté, & son bois est plus estimé; [...]

6. L'épicea ; c'est l'espece de sapin la plus commune en Europe, celle qui atteint une plus grande hauteur, qui se soutient le mieux dans un terrain médiocre, que l'on cultive le plus pour l'agrément, quoique ce soit l'espece de sapin qui en ait le moins. Il a l'écorce rougeâtre & moins cassante que celle du vrai sapin. Ses feuilles sont plus courtes, plus étroites, d'un verd plus mat & plus brun, & elles sont placées autour des nouvelles branches sans aucun ordre distinct. Ses cônes sont plus lisses & plus longs ; [...] Le bois de cet arbre sert aux mêmes usages que celui du vrai sapin : il est vrai que la qualité en est inférieure, mais il est moins noueux & il se travaille plus aisément.

This indeed explains much of the confusion between the two trees we regularly find in old sources: in the middle of the eighteenth century they were still regarded as variants of the same type of plant and anyway, from a practical point of view, both of them were employed in similar ways.⁴¹ Since we find extant French instruments which employed both kinds of wood and the use of the word *sapin* is ambiguous, we must conclude that either or both Fir and Spruce may have been intended by the authors of these treatises.⁴²

41 This is still partly true nowadays: in commercial wood assortments of lower quality, meant for rougher work, planks of Fir and Spruce are often mixed together.

42 For example Henri Hensch's harpsichords have soundboards out of Fir.

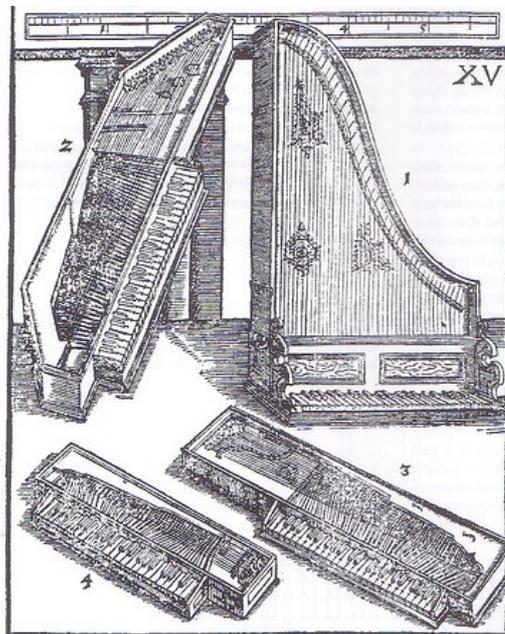
-German-speaking Countries

Despite the great tradition of musical treatises, very little is found in German sources on our topic before 1750. The most famous texts are not an exception to this general tendency. If one looks at **Virdung's** *Musica Getuscht* of 1511, which is said to be the first printed book to deal with musical instruments and to sketch an organological classification, very little is said on their actual construction.⁴³ The same is true for the treaty by **Martin Agricola**, which borrows much material from Virdung and which had many reprints during the sixteenth century.⁴⁴

In the seventeenth century German theorists did also not show much interest for organological descriptions; almost every musician is now familiar with **Michael Praetorius'** beautiful woodcuts.⁴⁵ They are indeed of great interest, as they document important evolutions in the construction of clavichords: the *Octav* clavichord has a single straight bridge perpendicular to the string similar to the fifteenth century style; the *Italian* clavichord has several, more or less straight, partial bridges, which appears to have been the standard practice in the sixteenth century;⁴⁶ while the *Gemein* clavichord, i.e. the common type, already shows a single curved bridge, as later instruments do. With all of his uncommon care for illustrations and descriptions, Praetorius, however, did not spend a single word on the wood that an actual maker should use to build a real harpsichord or a clavichord.

The same is true for the other major German theorist of those times: one can find pictures of singing birds, human throat and voice organs, *automata* and several European or foreign instruments in **Kircher's** *Musurgia Universalis*.⁴⁷ Among them there is, of course, a harpsichord, but the author frankly seems to be more interested in describing fancy enharmonic keyboards, than to give hints on how to make a real soundboard. Kircher's attitude in 1650 still matches that of most theorists from the Middle Ages, Renaissance and Baroque era: it was a noble occupation for scholars to speculate on possible tuning systems for keyboard instruments, dealing with complex geometrical and arithmetical divisions of the monochord; still they did not feel compelled to describe the handcraft process and materials. We have to wait until the eighteenth century to find some practical details; and indeed there are quite many coming from Germany.

One of the most important treaties is *Musica mechanica organoedi* by **Jacob Adlung**.⁴⁸ The manuscript of this work was written in the late 1720s, but it was only published some 40 years later, after the author's death. Adlung was born in 1699 near Erfurt and it is important to underline that he was not only a scholar, but also an amateur instrument builder. He was a pupil of Johann Nikolaus Bach, who was also an instrument builder, and was friends with Johann Gottfried Walther, another



1. Clavicytherium. 2. Clavichordium, Italianischer Mensur. 3. Gemein Clavichord. 4. Octav Clavichordium.

43 Sebastian Virdung, *Musica getuscht*, (Basel 1511).

44 Martin Agricola, *Musica instrumentalis deudsch* (Wittemberg, 1529).

45 Praetorius, *De Organographia*, Tables VI, XIV and XV.

46 This picture proves that Italian instruments were well known northern of the Alps during the Renaissance. This Clavichord has a bigger compass of 50 notes, C/E-f", which was widely used in the sixteenth century Italy, but rapidly came out of fashion in the seventeenth in favor of the "standard" 45 C/E-c" keyboard. It's curiously one of the few instances known to me in instrument's development, where a reduction of the keyboard compass took place.

47 Kircher, *Musurgia Universalis*.

48 Jacob Adlung, *Musica mechanica organoedi* (Berlin, 1768). Since this text, as many books from the Baroque period, is organized in paragraphs, I will include the paragraph number in the quotations without reporting the page number. This is useful when consulting one of the several digital versions of the text, because pages never correspond to the original and a lot of scrolling is needed just to read the page number.

leading theorist of that period. Before discussing materials and construction, it is useful to quote how a good instrument should sound according to Adlung's judgment:

§. 582.

Ein Clavichord soll stark klingen, jedoch aber nicht so pochend, sondern lieblich, auf Harfenart. Es soll auch lieblich und lange nachklingen. Dieses ist eben der Punkt, welcher den Instrumentmachern viel zu schaffen macht, und gerathen die Clavichordien selten nach ihrem Kopfe. Ja, ich habe gesehen, daß einer die Körper zweyer Clavis

Praising loud-sounding clavichords with good sustain and sweet, harp-like, singing tone, he says that trying to make such an instrument is one of the main points of instrument builders of his time. Speaking of the clavichord's soundboard, he sends us back to the *Clavessin* chapter, reinforcing implicitly the assumption of many other authors, that the two instruments share the same building principles in this important aspect:

§. 508.

Alsdann macht man die Decke über das ganze Clavessin von subtilen Tannenholze. Denn dieß Holz ist leichter, als das meiste andere, daher es durch die Luft am leichtesten beweget wird, folglich auch den Klang am besten befördert. Es muß aber recht dürre seyn, sonst würde es im dünnen Wetter schwinden und springen, und durch die daher entstehenden Ritze der Klang nachgehends gehemmet werden. Der Boden (so

“Tannenholz” is the specific German word for Fir. Adlung adds that this wood is lighter than others and is used for this reason. He also immediately points out the other most relevant characteristic of soundboard wood: it must be well dried out. In the following chapters he gives us other precious details:

§. 523.

Das Holz zu der Decke muß nicht fetticht seyn. Es pflegen dahero einige Instrumentmacher solche Bretterchen, welche sie zu Decken brauchen wollen, zuvor wohl auszusieden, welches in einer Brauspanne am füglichsten geschehen kann. Alsdann leimt man sie accurat zusammen. Dicker dürfen sie nicht seyn, als etwann den 16ten Theil eines Zolles, damit die Decke sich leichter bewegen lasse und zum Zittern gebracht werde. Wenn man etwas auf den Steg legt; so wird der Klang stiller, weil das Zittern so frey nicht geschehen kann. Wenn man sonst auf die Decke etwas legt, z. E. einen Schließel oder sonst etwas; so rasselt es: woraus man siehet, die Decke müsse durch den Anschlag stets in Bewegung gebracht werden. Man findet, daß neue Clavicymbel (wiewol es bey den meisten musikalischen Instrumenten eintrifft) nicht so angenehm und scharf klingen, als wenn sie eine Zeitlang gespielt worden. Die Hauptursach ist, weil das Holz immer dürrer und leichter wird. Daher etliche nicht unrecht thun, wenn sie alte Kästen ꝛc. dazu nehmen, die man lange Zeit an dünnen Orten liegend gehabt, daß sie recht haben ausdörren können. Auch pflegt man die Decke im Basse etwas dicker zu machen, der Gravität wegen. Unter die Decke kommt ein Wiederhalt zu stehen.

First of all, wood has not to be “fetticht” (word used for greasy or dirty); he is possibly referring to rosin deposits and other impurities. Secondly Adlung is describing for the first time a practice of treating soundboard wood by means of warmth. This practice, as he puts it, may however not have been the standard in the eighteenth century, but just a method of some builders. Thirdly, he reports the practice of some other makers to reuse old wood from furniture pieces, for it has had more time to dry out completely.

This is exactly what it is reported that **Gottfried Silbermann** was doing:⁴⁹

hatte. Ich sagte ihm, wie Andern, Schlesien habe das beste Holz, nur daß man älters nehmen müsse als man bisher nicht genommen habe, *) unfrö

*) Silbermann reiste auf den Dörfern umher, um den Bauern neue Kirchstühle bauen zu lassen. Das Holz ihrer alten, welches denn über hundert Jahr alt war, nahm er statt des Arbeitslohns.

To make another example of eighteenth century drying out practices, Mozart, writing in 1777 to his father about **Johann Andreas Stein's** fortepianos in a very enthusiastic manner, describes the master's method of preparing durable soundboards in this way:

Er sagt oft, [...]

["] allein ich bin halt ein Liebhaber vom Instrumenten die den Spieler nicht ansetzen, und die dauerhaft sind["]. seine Clavier sind auch wirklich vom Dauer. Er steht gut davor daß der Resonanceboden nicht bricht, und nicht springt. Wenn er einen Resonanceboden zu einem Clavier fertig hat, so stellt er ihn in die Luft, Regen, Schnee, Sonnenhitze, und allen Teufel, damit er zerspringt, und dann legt er span ein, und leimt sie hinein, damit er recht stark und fest wird. Er ist völlig froh wenn er springt; man ist halt hernach versichert daß ihm nichts mehr geschieht. Er schneidet gar oft selbst hinein, und leimt ihn wieder zu, und befestigt ihn recht.⁵⁰

It seems reasonable to conclude that from the fifteenth to the eighteenth century, while other systems may have been tried, this type of “natural” seasoning process, of course with some variations from one maker to another, was widely preferred, since the amounts of soundboard wood required were still compatible with the slow rhythm of this practice. From the beginning of the nineteenth century, however, when the demand for new pianos literally exploded, especially in Vienna many thermal or steam-driven treatments began to be employed on a larger scale and on a more regular basis.

Adlung states that the soundboard shouldn't be too thick or it won't vibrate freely and he also gives a concrete thickness indication: 1/16 of an inch. Unfortunately it is difficult to establish precisely a metrical equivalent, since it is not known exactly which inch he was referring to. Since historical inches measured typically between 30 and 24 mm, one sixteenth means something between 1,5 and 1,9 mm, which is fairly thin. Of the extant instruments, however, no one has such a thin soundboard over the whole compass, but some approach these values in the very top treble. Since Adlung also states that the bass region is normally made thicker, this may partly explain these uncommonly low values.

49 *Schlesische Provinzialblätter*, Jahrgang 1785, Band 2, pg. 439. This source is available on: ds.ub.uni-bielefeld.de/viewer/toc/2233737/1/

50 Wolfgang Amadeus Mozart, *Brief, Augsburg 17-X-1777* now in Salzburg, Internationale Stiftung Mozarteum; Bibliotheca Mozartiana. Mozart's correspondence is available on <http://dme.mozarteum.at>

Johann Samuel Halle was an art loving scholar and not an instrument builder, but in his monumental work *Werkstätte der heutigen Künste*, published in several books between 1761 and 1779, he gives us many valuable insights on a number of different crafts of his time.⁵¹ In the chapter dedicated to organ builders he has a sub-chapter for other instrument makers, somewhat underlining the strong connection between the one with the other. One of this paragraphs is dedicated to the “Flügelmacher” i.e. to harpsichord maker, and he goes into some interesting details about gluing a soundboard and choosing the right wood:⁵²

unbiegsam bleibt. Man nimmt auch zu den Resonanzboden Tannenholz, und man leimt sie aus tannenen Brettern, die $\frac{1}{8}$ Zoll dünne, und oft dünner sind, zusammen, da sie denn schon in der Leimzwinge, wenn man mit einem Finger daran schlägt, einen dumpfigen Laut von sich geben. Man macht also die Körper, der Flügel gemeinlich aus Ahorn, und den Resonanzboden aus Tannenholze, doch mit dem Unterscheide, daß die Mittagsseite einer Tanne, weil ihre Fasern von der Sonne feiser und härter gebrannt sind, der Mitternachtsseite, welche den Klang der Saiten am besten unterhält, und deren Fasern am leichtesten zu erschüttern sind, den Vorzug läßt.

He is, like Adlung, clear on his preference for Fir and also gives an interesting hint about avoiding too hard fibers, such as it happens in his view on the south-oriented part of the trunk. Moreover, in the chapter describing the joiner, he adds an important description of the actual characteristics of the tree.⁵³

Die Tanne von weißlicher Rinde, aus welcher die Knoten oder Nadelbüschel herausbrechen; diese geben geritzt ein flüssiges Harz. Eine jede Schuppe des Zapfens versteckt 2 Saamenkörner, deren Oberteil geflügelt ist. Die spitzen und länglichten Nadeln umgeben nur eine Seite des Stiels, da sie an der Fichte rings um geordnet sind. Sand und Anhöhen sind ihr Boden. Das Holz ist weich, feinadrig und weiß, mit wenigereim Harze erfüllt. Man bringt es zu uns aus Sachsen. Man macht allerlei Tischarbeiten aus den tannenen Brettern, besonders dient es zu den Schachteln, und aus dem feinsten werden die Resonanzboden der Flügel, Klaviere, Harfen, Geigen und Zittern geschnitzt.

This is one of the rather few instances where we can be totally sure which actual tree the author was referring to: it is inarguably Fir. Halle in addition correctly names and describes several other softwoods, like Pine, Spruce, Larch and Cypress, so there is no room for confusion. Finally he states that this wood comes from Saxony.

When speaking of the final planing to thickness of the soundboard he gives the value of 1/8 of an inch. Again we cannot be sure of which inch he was referring to, but it is exactly twice as much as indicated by Adlung (i.e. around 3- 3,8 mm). It is indeed a reasonable guideline for the average thickness of a soundboard and is in accordance with most of the surviving instruments.

51 Johann Samuel Halle, *Werkstätte der heutigen Künste oder die neue Kunstgeschichte*, (Brandenburg und Leipzig, 1764)

52 Halle, *Werkstätte der Künste*, III volume, 358.

53 Halle, *Werkstätte der Künste*, III volume, 46.

Also not an instrument maker, but an admirer of handcrafts, was **Peter Nathanael Sprengel**, who was appointed professor at the *Realschule* in Berlin. Since his superintendents wished arts and crafts to be taught at that school, from 1767 on, he started publishing the 17 volumes of his work *Handwerke und Künste in Tabellen*, where he describes several workshops and their activities with help of descriptions and illustrations.⁵⁴ Volume 11 deals with crafts that use wood as a main starting material, so joiners and several instrument builders are represented. From the richness of details one has the impression that Sprengel (or one of his collaborators) personally went to real workshops in order to document their actual and up-to-date (1770s) practices:

Wichtiger ist nach dem gegenwärtigen Zwecke die Verfertigung des Resonanzbodens, [...] Er kann nur aus Tannenholz verfertigt werden, weil dieses Holz vorzüglich elastische und klingende Holzfasern hat, und weil es überdem wenig Harz bey sich führet. Der Künstler erhält dieses Holz aus Böhmen und aus dem Schwarzwalde in kleinen Brettern, die $\frac{1}{2}$ Fuß breit, $\frac{6}{7}$ Fuß lang und $\frac{1}{4}$ Zoll dick sind. Der innere Kern der Tanne hat zu dem gegenwärtigen Gebrauch zu grobe und Starke holzfasern, und die gedachten Bretter können daher nur aus dem Holze der Tanne neben diesem Kern gespalten werden. Daher kommt es auch, daß diese Brettern nur schmal sind.

[...] Was für eine Dicke muß aber der Künstler diesem Resonanzboden beym Behobeln geben? Er hat keine gewiße Regel, sondern er bestimmt diese Dicke blos nach seinem geübten Augenmaaße. Soviel läßt sich ohngefähr sagen, daß jeder Resonanzboden etwa $\frac{1}{8}$ Zoll dick seyn muß.⁵⁵

Sprengel is categorical in his wood choice: *only* Fir is suitable. The fact that he points out that Fir has little rosin is precise enough to let us safely conclude that he was well aware of the differences between Firs and Spruces. He goes so far as to name the places where the soundboard wood available in mid eighteenth century Berlin came from: Bohemia and the Black Forest. This, together with Halle's remarks, are indeed a precious indication, because many historical authors did not spend a word on wood provenance and yet, the same kind of lumber, grown in different regions usually has rather different characteristics, due to climatic and genetic factors. Indeed, wood coming from the two different sides of the very same valley can, due to environmental factors like height, wind streams, water distribution and sun irradiation, be very different.

His consideration about avoiding the center of the trunk is indeed not surprising and corresponds to the most empirical woodworking rules: since this part of the tree has very widely spaced annular rings and the area around the pith tends to split while drying out, no one really wants them to be incorporated into a soundboard. Some authors translate this passage as an indication to avoid heartwood and use only sapwood instead.⁵⁶ This may seem another possible interpretation of the text, but makes much less sense when applied to the real tree: in Fir trunks, in fact, sapwood and heartwood cannot be distinguished either by color, or by other means. I tend to think that Sprengel is just suggesting to avoid the center of the trunk, which corresponds to the first years of life of the tree, and is usually grown fast and full of faults.

About the final thickness he gives an approximate value of $\frac{1}{8}$ of an Inch, thus perfectly matching Halle's indications. But since the final thickness is process-oriented, as it depends very much on the wood itself, he admits that this is only an indicative value and that craftsmen work following their expert eyes.

54 Peter Nathanael Sprengel and Otto Ludwig Hartwig, *Handwerke und Künste in Tabellen : Mit Kupfern ; Elfte Sammlung: Bearbeitung des Pflanzenreichs* (Berlin, 1773).

55 Unfortunately this so often cited work is not yet available in a digitalized version and printed copies, as one can imagine, are rare. So I'll have to refer to a quotation of the article "Von dem Clavier" found in *The Organ Yearbook*, 19 (1988): 104-131. I will refer to the original German text and not to the English translation provided there. It is worth to note Sprengel's entry on the harpsichord very often send back to the clavichord's description.

56 Klaus, *Tasteninstrumente*, 79.

There is another, now and then cited, eighteenth-century source dealing with this topic: **Jacobsson's** *Technological Dictionary*.⁵⁷ Since Jacobsson was working on this book together with Sprengel's former collaborator, Hartwig, it is indeed not so surprising that his work quotes the prescriptions for soundboards contained in *Handwerke und Künste in Tabellen* word for word. I thus don't regard it necessary to comment on this text separately.

The last source I will report for German soundboard practice, comes from America. **David Tannenberg** was a Saxon maker, who emigrated to Pennsylvania in 1749, together with a group of Moravian colonists. In 1765 he started his own organ building workshop; the new communities coming from Europe were building new churches and, especially by German congregations, there was a high demand for organs. By the end of the century Tannenberg was working simultaneously on several commissions and was completely booked out. It must have been a very hectic period in his workshop in the 1790s. That's probably why he around that time he sent plans for building a clavichord to the Moravian community in North Carolina, who had already contacted him for two organs. If he, as we can easily imagine, would never have come to build the clavichord himself, as he was too busy with organs, it seems to be reasonable that he may have sent plans in order for some local craftsman to work on them. Tannenberg, however, was not aware of the newest tendencies in his motherland since he left, so his clavichord in its layout and compass seems to be more representative of instruments built around the middle of the eighteenth century, than toward the end. His instructions included drawings, a full scale rack pattern drawn on parchment (now lost), and written instructions on how to proceed. About the soundboard he says:

Die Resonanzdecke muss vom gutem Holz gemacht werden (Ihr werdet wohl kein anderes als Spruss-Pint haben.) Wenn dieselbe nach ihrer Grösse verleimt und auf einen 1/8 Zoll ausgehobelt ist, so wird zuerst der Steg darauf geleimt, und wenn der trocken ist, so wird auf der inwendige Seite eine Rippe L etwa 1/2 Zoll hoch und etwas über 1/4 Zoll dick aufgeleimt. Sie kann auch noch ein bisschen stärker sein und noch 3/4 Zoll hoch. Die läuft unter dem Steg durch und bleibt mit beiden Enden einen 1/4 Zoll von der Seite ab. Wo dieselbe unter dem Steg läuft, schneidet man die Rippe ein bisschen hohl, damit der Steg und die Rippe nicht gerade unter einander fest sind.⁵⁸

This short text is of incredible importance to document the (or one) actual order of the building process and the practice of undercutting bars passing under the bridge. He also gives thickness values for ribs and soundboard and the latter also coincides with indications from Halle, Sprengel and Jacobsson.⁵⁹ Speaking of wood, however it is much more difficult to draw safe conclusions on what he means by “Spruss-Pint”. To begin with, this word doesn't exist at all in German; but since English was the most spoken language in northern America, it is possible that Tannenberg was using a misspelled form of “Spruce-Pine” to avoid confusion with wood suppliers or craftsmen who were to build the instrument. On the other hand he does not use English terminology for any other parts. It could also be that he is actually pointing to an American indigenous tree that did not have any German name and was different from common European species (which may partly explain why he adds “you won't well have any other”). Still it is not clear why he then simply specifies “Fichte”, also regular Spruce, for the bottom. It seems anyway reasonable to assume that the type of material Tannenberg had in mind for his soundboards was some kind of Spruce-like wood, yet no more specific conclusions can be made.

57 Johann Carl Gottfried Jacobsson, *Technologisches Wörterbuch*, Part 3, Berlin 1783

58 McGeary, “David Tannenberg,” 94-106.

59 As pointed out before, one cannot be sure of which actual inch these authors are speaking. But since these are meant to be approximate directions and their difference, dividing different Inches by 8, makes out just some tenth of a millimeter, they are still meaningful guidelines.

-Italy

Italy is one of the most important countries when it comes to the earliest repertoire. In the early Renaissance, many northern composers traveled south and worked in the wealthy Italian courts, while in the late Renaissance and early baroque, Italian composers were appreciated all over Europe and their style was spread abroad by many of their pupils. We are lucky that in the period 1480-1630 several musical treatises were published in Italy, as they are indeed precious testimonies on the evolution of harmony, counterpoint, temperament and performance practice. After this golden age one has the impression that the importance and quality of keyboard music, with obvious exceptions, generally declined. This may seem a very personal and modern evaluation, and perhaps it is, but on the other hand it is indeed what several foreign musicians of the eighteenth century report to us in their commentaries. Charles Burney, in an often quoted lapidary sentence says:

But to say the truth I have neither met with a great player on the harpsichord, nor an original composer for it throughout Italy. There is no accounting for this but by the little use which is made of that instrument there, except to accompany the voice. It is at present so much neglected both by the maker and player, that it is difficult to say whether the instruments themselves, or their performers are worst.⁶⁰

Burney is surely known for exaggerated complaints about foreign countries in his writings. But I'm rather sure that he couldn't have gotten the same impression if he would have visited Venice in the times of Claudio Merulo and Giovanni Baffo.

A special consideration must be made on clavichords and on the overall evolution of Italian instruments: while all of the oldest, sixteenth-century clavichords preserved are of Italian origin, it seems that their production was discontinued, with only few exceptions, after 1630. This may hint to a change in the musical taste after this date.

More generally, despite the fact that all Italian harpsichords look somehow similar from the outside (single keyboard, thin case, elongated shape), it seems that a major change in the field of plucked instruments took place at the beginning of the seventeenth century:⁶¹ together with the decline of Venice as a major center of instrument building, the common Renaissance compass C/E-f^{'''} disappeared, the early 1x8', 1x4' disposition came rapidly out of fashion for the 2x8' one⁶². Cypress progressively lost its role as main building material for soundboards, the orientation for the scaling design became the Cs instead of the Fs.⁶³ Also crucial from the constructional point of view, was the transition from longer iron scales (c" around 330 mm) to shorter brass scales (c" around 270 mm): most early instruments were later rebuilt in that way moving either or both bridge and nut to be suitable for brass stringing and probably for a different pitch.

This evolution and most other details about instruments' construction were never registered in written sources, as none of them goes into details of building. **Nicola Zarlino's** praise of **Dominicus Pisarenis**, who had built his *Archicembalo*⁶⁴ is probably one of the first documented

60 Charles Burney, *The present state of Music in France and Italy* (London, 1771), 207-298.

61 Denzil Wraight, *The stringing of Italian keyboard instruments c.1500 – c.1650* (Ph.D. diss., University of Belfast, 1997)

62 This became the norm for later harpsichords. Many older instruments were adapted having the 4' bridge removed.

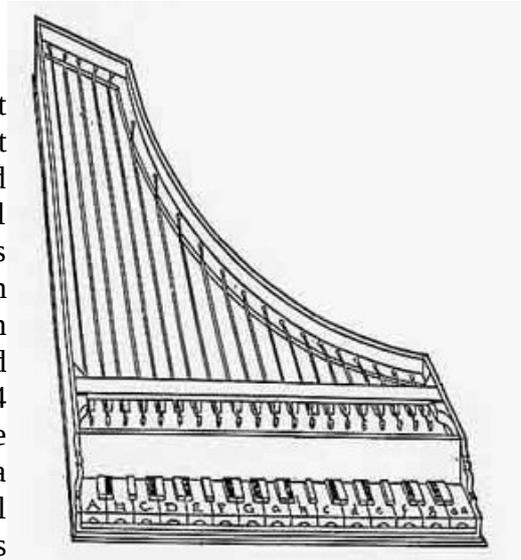
63 This is true also for organs: while during the Renaissance 24', 12', 6' or 3', F-based organs were the norm, in the seventeenth century 16', 8' or 4', C-based organs became the standard. The change was more gradual than in stringed instruments and older organs were often not rebuilt, unless other reasons made it necessary.

64 Gioseffo Zarlino, *L'Istitutioni Harmoniche* (Venezia, 1558). *Archicembalo* is the name applied to harpsichords with 19 or more notes per octave, that allows the player to play enharmonically on the basis of a meantone temperament. With 1/3 comma meantone with pure minor thirds, for example, the chromatic semitone is almost exactly half as wide as the diatonic one. In this system double flats coincide with the sharps of the lower tone (i.e. Ebb is D#) and double sharps with the flats of the upper notes (i.e. D## is Eb) and apart for the normal split sharps for each chromatic key, practically only two additional keys are needed (E#/Fb and H#/Cb) to obtain a closed system. In

cases of endorsements by an influential musician to a builder:

[...] perciocché uno de tali istrumenti feci fare l'anno di nostra salute 1548 in Vinegia, per avere nella musica una cosa che fusse quasi simile alla pietra che si esperimenta l'oro e l'argento; acciò potesse conoscere e vedere in qual maniera potessero riuscire le armonie cromatiche e le enarmoniche e ogni sorte di armonia che si potesse avere da qualsivoglia divisione; e fu un gravecembalo ch'è anco appresso di me, il quale fabricò maestro Dominico Pesarese, raro ed eccellente fabricatore de simili istrumenti, nel quale non solamente i semitoni maggiori sono divisi in due parti, ma anche i minori, di maniera ch'ogni tuono viene ad essere diviso in quattro parti⁶⁵

Here Zarlino explains us that in 1548 he had let Dominicus Pisarensis, “rare and excellent” instrument maker, build him an enharmonic harpsichord, which would allow him to experiment “every sort of harmony”. With all his appreciation of Pisarensis' work, Zarlino, as all of his contemporaries, seems however frankly more interested in enharmonic monochord divisions than in soundboards. In fact the only notable characteristic about this harpsichord that he felt compelled to describe is the fact that it had 24 keys per octave: its unusual keyboard seems indeed the only reason for mentioning it, as the author did not spend a word describing anything else. Again, we have to wait until the eighteenth century to find a new attitude towards practical building matters.



Scipione Maffei was a writer and historian born in Verona, who had traveled much and had several contacts in other countries for he had served in the Bavarian army. In 1710 he started a literary journal in Venice, in which several different topics were discussed and also in which much space was given to new inventions.⁶⁶ Among other articles, he publishes in 1711 the first description of Cristofori's Fortepiano. Maffei's attestations are important, as he was interested in reporting details about construction, which he had learned directly from Cristofori during a visit to the master in 1709. He also reports about the rather cold reception that Cristofori's piano had received in Italy, due to his less brilliant sound and smaller (!) volume compared to harpsichords. Possibly this article and its famous German translation by Mattheson⁶⁷ are the main reasons why Cristofori's invention did not share the destiny of other more short-lived innovations in instrument building history.⁶⁸

this way one approaches an equal temperament based on a 19 third-tone division of the octave. The picture in *L'Istitutioni Harmoniche* shows such a division; some scholars, however have suggested that Zarlino's harpsichord, according to his descriptions, may have had 24 or even 31 keys per octave.

65 Zarlino, *Istitutioni*, 140-141.

66 *Giornale de' letterati d'Italia*, issued in Venice from 1710 to 1740.

67 Johann Mattheson, *Critica Musica*, Band 2, Hamburg 1725.

68 Mattheson's translation of Cristofori's interview was probably read and taken as source of information by Gottfried Silbermann for his Fortepianos.

Luckily enough for our purposes, Maffei's interview, gives us indications of the wood used by two important masters: Pisarenis and Cristofori.⁶⁹

mill'altre considerazioni. Non è anche da tralasciare, che tenendosi universalmente, che siano sempre imperfetti i graveceembali nuovi, e che acquistino perfezione solamente col lungo tempo; pretende questo artefice, che si possa lavorargli in modo, che rendano subito sonora voce non meno de' gli stromenti vecchi. Afferma egli, che il non risonar bene de' nuovi nasce principalmente dalla virtù elastica; che per qualche tempo conservano la sponda incurvata, ed il ponte; perchè, finchè questi fanno forza sul fondo per restituirsi, la voce non vien perfetta: che però se questa virtù elastica sarà loro tolta interamente prima di porgli in opera, verrà subito a levarsi questo difetto, com'egli in pratica esperimenta. Contribuirà ancora la buona qualità del legno: onde il Pefaro si cominciò a servire de' cassoni vecchi, che trovava sopra i granaj di Venezia, e di Padova, e ch'erano per lo più di cipressi di Candia, o di Cipro.

Here Mattei is reporting the eighteenth century belief (still in circulation today) that new harpsichords do not sound as well as old ones. Cristofori is evidently speaking to his interviewer about the negative influence that the string tension and down-bearing pressure on the bridge had on the sound of a new, not yet stabilized instrument. He also claims to have found a remedy to this inconvenient and states that using best quality wood helps avoiding this long playing-in phase. Cristofori was working as instrument keeper at the Medici court in Florence, which is said to have had four instruments by Pisarenis and in 1693 he also carried out repairs on two instruments by the Venetian master. He himself was born in Padova some 80 years after Dominicus' death so, although apparently distant in time and space, Cristofori may have been well informed on the activity of his older colleague.

When I, some years ago, first read this description about a famous instrument builder of the Renaissance reusing wood from crates from old barns, I dismissed the idea as a legend, because in my mind a self-respecting builder should only have used the best virgin wood in his instruments. Now I tend to think that this "legend" was indeed true; not only several other attestations about the

69 Scipione Maffei, "Nuova invenzione d'un Graveceballo col piano, e forte," *Giornale de' letterati d'Italia* 5 (1711): 156-157.

use of old wood can be found in sources, but traces of reused wood have actually been found in several instruments from the Venetian tradition during recent restorations.⁷⁰ Maffei also gives one of the few testimonies on the evolution of soundboard roses in Italy:

Essendo questo ingegnoso uomo eccellente anche nel lavorare grave-cembali ordinarj, merita di notarsi, com'egli non sente co' moderni artefici, che per lo più gli fabbricano non solo senza rosa, ma ancora senza sfogo alcuno in tutto il cassa. Non già ch'egli creda necessario un sì gran foro, come erano le rose fattevi dagli antichi, ne che stimi opportuno il forargli in quel sito, ch'è sì esposto a ricever la polvere; ma suol'egli farvi due piccoli buchi nella fronte, o sia nel chjudimento davanti, che restano oc-

This is not directly linked to the material used, but is interesting to quote, as it underlines yet another change between earlier and later Italian instruments. Cristofori here reports that the ancient harpsichords had big roses directly on the soundboard, but his contemporaries often did not make openings at all. He states that holes of some kind are acoustically important and that he used to make them on the belly rail, where no dust could enter.

Another interesting attestation of the use of Cypress is found in **Adlung**. This passage is never quoted in books dealing with stringed keyboards, because it actually speaks about wooden organ pipes.⁷¹

§. 95.

3,) Von den hölzernen Pfeifen. Da fragt sichs erstlich: Was für Holz dazu zu nehmen? Antw. Die Natur eines jeden Holzes giebt uns die Antwort in den Mund. Das Erlenholz vermodert, wenn es nicht in sumpfigten Oertern stehet; Eben- und Brasilienholz ist hart zu arbeiten, dabey auch sehr kostbar; Eschen- und Ilmen- wie auch Pappelholz ist ebenfalls schwer zu arbeiten. Die Tanne bleibt fein gerade, und ist gut zu arbeiten: aber die Würmer gehen sie bald an. Cedern- und Cypressenholz laßt sich auch gut arbeiten, und ist auch von den Würmern frey; und was in der Physik mehr vom Holze gemeldet wird. Die drey letztern Arten schicken sich gut zum Pfeiswerke; doch muß man das Tannenholz durch die massam (§. 38.) vor den Würmern verwahren. Das Cedern- und Cypressenholz ist beydes hier zu Lande viel zu rar, als daß man große Werke davon aufführen sollte, daher man es selten gebraucht. In der Görlitzer Orgel ist die Quintaton 16' und die Onda maris meist von Cypressenholz, sonderlich in den obern clauibus. Es ist auch dieses Holz weder bey kalt- und feuchten Wetter, noch bey warm- und trockenen einiger Veränderung unterworfen. Das Tannenholz, und, welches gleiche Natur hat, das Sichtenholz wird also bey uns gebraucht. Das Lichenholz kann aber auch einique Dienste

70 Cf. Andreas Beurmann, *Historische Tastensinstrumente* (München, 2000). Particularly instruments n. 2 and 9.

71 Adlung, *Musica mechanica*.

The importance of this paragraph has probably been overlooked: Adlung attests that the dimensional stability of Cypress and its resistance to woodworm were well known and appreciated in historical times, even in regions where this wood was not common. These might very well be some of the reasons why Italian masters chose to use this particular wood. Finally Adlung also states that Fir and Spruce have the same “nature” and, at least for organ pipes, they can both be used in a similar way.

Despite the fact that all Italian instruments are thought to look similar, half a dozen different regional traditions can be linked to different centers of production, which in historical times actually belonged also to different States. Indeed Italy was perhaps the country where most experimentations with soundboard materials took place: we range from the traditional Italian Cypress and the more internationally used Fir and Spruce, to Maple and even Marble!⁷² This big variety surely has partly to do with the very different climatic conditions on the peninsula, partly with the regional fragmentation, partly probably with taste and artistic or practical consideration. Still, as I already mentioned, unfortunately for this research, no other written sources about those other traditions could be identified.⁷³

In any case, regarding the Venetian school of the golden age and Cristofori's own practice, Maffei's article is reliable, as it matches the evidence from the surviving instruments: Cypress was the wood used throughout, not just for soundboards. There is little reason to doubt that the wood used was coming from the apparently far islands of Cyprus and Crete, as both were under Venetian domain during Pisarenis' times.⁷⁴

72 One harpsichord almost entirely made out of Carrara-Marble is preserved in Modena. It was made out a single piece of Marble in 1687 by Michele Antonio Grandi for Francesco II d'Este. It's soundboard has a thickness between 6 and 2 mm.

73 It is to believe that some other sources may still lie unpublished in some dusty Library: one cannot completely escape the impression that Italian instruments, music and sources did not yet really attract the attention of most scholars and musicians. There are many studies on specific northern makers like Silbermann, the Hass, the Ruckers; but despite the fact that today the astonishing number of 15 extant instruments can be attributed to Dominicus Pisarenis, which survived from the period 1533-1575, no study was yet undertaken neither on the work of this master, nor on any of his colleagues.

74 Entries in the Medici archives attest payments for both local and Crete's Cypress, that Cristofori needed for repairing and building instruments. These are quoted at length in Raymond Russell, *The Harpsichord and Clavichord* (London, 1959).

-Spain

Unfortunately, extremely few historical keyboard instruments have survived from Spain and Portugal; on the other hand very few has been written on Iberian harpsichords and clavichords in modern times. Some scholars report that playing an instrument was not much considered by Spanish noblemen, still at least musicians who lived there will have needed some sort of instrument to perform on.⁷⁵ Even assuming the possibility that the rich and powerful Spain may have bought instruments from southern Italy or Flanders (countries that had strong political connections to Spain), is still hard to explain why only about a dozen of harpsichords and clavichords survive.⁷⁶

Fortunately, at least one book deals with their construction in details: *Escuela musica* by Pablo Nassarre, a blind Franciscan who was organist in Zaragoza.⁷⁷ The book deals with several aspects of musical education and practice of the times; it also describes some musical instruments, their construction and use. Nassarre seems to care very much about the proportions of the instruments and particularly of the dimensions of their sound-chest, which he calls *concavo*. Indeed the whole chapter XVI, devoted to stringed keyboards, is entitled “*De las proporciones que deven observar los Artifices en los Instrumentos*” and this title also makes clear that Nassarre's prescriptions are directed to builders. In this regard he also expresses the exact contrary attitude towards craftsmen than the one we find in eighteenth century German and French authors: while the latter went into a real workshop to gain knowledge for their texts, one has the impression that Nassarre, who likely never had direct building experience, wants to direct the craftsmen's work through his theory of proportions.⁷⁸ In other regards, however, Nassarre seems to be well informed of contemporary workshop activities: speaking about materials for the soundboard he tells us about failed experiments with instruments out of ebony.⁷⁹ He makes a general discussion about all instruments which have soundboard and strings and is rather clear about the characteristics of the right wood:⁸⁰

¶^o Son Trompetas, Flautas de Organo, y otros. Todos aquellos que son de madera, se han de elegir las maderas fuertes para fabricarlos, y que sean lisas; pues es circunstancia, segun doctrina de los Filósofos. Las tapas de los Instrumentos, sobre quienes cargan las cuerdas, ha de ser una madera porosa, y segun la experiecia castelana, la mas al caso es el Pino avete, importa que sea delgada, para que sea mas resonante en el concavo el sonido.

El ser mas solidas las otras maderas, que forman el concavo, no importa menos, por la razon de que hecida la cuerda, mueve el ayre, y con el dicho movimiento entra por los poros de la tapa en el concavo, y mueve al que ocupa este, con el movimiento hiere ya en los extremos de la longitud, ya en los de la latitud; y este blando movimiento del ayre, que hiere en la materia lisa, y solida, causa el sonido m. dulce, y apacible. Todo esto confirma Aristoteles, pues dize, que por

75 Edward L. Kottick, *A History of the Harpsichord* (Bloomington, 2003), 233 et seq.

76 Indeed some historical clavichords survive in the former Spanish colonies of Latin America and they all show very conservative features.

77 Pablo Nassarre, *Escuela musica* (Zaragoza, 1724).

78 As usable proportions he refers to several classical proportions and he calls them with the name of their musical intervals like octave (2:1), twelfths (1:3) and fifth (sesquialtera, 3:2). Since this were (and are) the most important musical proportions both for rhythm or notation and speaking length of pipes and strings, it would be indeed not unlikely that instrument makers of Nassarre's time, following intuitive analogy, actually tried to build this proportion in their instrument.

79 He is in this case not directly referring to keyboard instruments.

80 Nassarre, *Escuela*, 450.

In this passage Nassarre informs us that the right material for the soundboard of all instruments with strings is the porous “Pino avete”. Moreover it's important that the soundboard (*tapa*) is thin (*delgada*) and it has to be smooth (*lisa*) and solid (*solida*) in order to give a sweet and gentle sound. In the following paragraph, he is also clear about leaving thickening matters to the builders themselves:⁸¹

ayre que es herido con la cuerda por sus poros en el *concavo*. Queda á la discrecion del Artifice la delgadez de las maderas , de modo que puedan resistir la violencia de las cuerdas.

Convieniẽ tambien que las maderas sean cortadas en menguante de Luna; porque cada una de ellas , de qualquiera especie que fuere , es mas *solida*, y permanentes y el Artifice podrá dexarla mas *lisa*, porque por la parte interior del *concavo* importa que lo estè, por la reflexion del *sonido* (segun se puede inferir de las doctrinas que puse arriba de

The prescription of observing lunar phases while cutting trees, in this case waning moon, is particularly interesting. It reflects ancient traditional beliefs on wood-felling and is still respected by some soundboard-wood suppliers, so it's worth making a short digression on this topic.

The Idea that season and moon phase played an important role in the characteristics of the final wood, can be traced back at least to the botanical treatise of Theophrastus (372-287 B.C.), which very influential in the Renaissance; the fifth book deals entirely with wood.⁸² Indeed in historical times, respecting moon phases was not only a spontaneous practice of lumbermen, but was it also fixed in the forest's regulations of several countries. Winter was always regarded as the right season to fell trees, but while firewood was to be felled at waxing moon, for construction wood the opposite rule was true. In this way it was believed to be more solid, less likely to be attacked by insects and more resistant to fire.

Despite the modern reader may think these opinions belong completely to the realm of superstition, recent scientific research focused on Spruce was able to prove a better drying behavior for trees felled in winter.⁸³ In the cold season trees are at rest, so the humidity content of the trunk is at its lowest point and it also contains less substances that attracts insects: this are clear advantages for faster and safer seasoning and durability. Evaporation is also lower in winter, so there is more time for transportation and sawing before risking the trunks to crack badly. It was also possible to establish a statistically relevant correlation between moon phase and dry weight: wood felled at waning moon, despite showing no differences at the moment of felling, tends to be ca 10% denser and harder once it is dried out. So Nassarre's opinions are indeed scientifically correct: wood fallen at waning moon (sometimes also called towards new moon) is generally more solid and resistant.

81 Nassarre, *Escuela*, 450.

82 Theophrastus of Eresos, *Historia Plantarum* (V, 1, 3)

83 Ernst Zürcher, *Lunar Rhythms In Forestry Traditions – Lunar-Related Phenomena In Tree Biology And Wood Properties*, 2001. This article is found on: http://www.researchgate.net/profile/Ernst_Zuercher/publications .

About clavichord ribbing the author gives us the following indications:⁸⁴

**fer tambien dura y folida, como en todos los demàs. La tapa importa
fer tambien la madera de Pino avete, y delgada, aunque se ha de for-
tificarse con dos, ò tres puentes, bien encolados en ella, que esten por
la parte del concavo.**

Two or three ribs well glued on a thin table of *Pino avete*. It sounds like a well thought-out plan; unfortunately it is much more difficult to establish which kind of wood Nassarre had in mind with his ambiguous terminology: some authors traduce “pino avete” with Spruce, which may or may not be correct.⁸⁵ It seems to me to be a little more complicated than that: first of all both “Pino” and “Abete” in Latin languages can loosely be applied to different coniferous trees. Interestingly also the modern scientific classification seems to reflect this use: *Pinaceae*, the family of the *Ordo Pinales* to which most of the trees discussed here belongs, means literally “Pine-like trees”. This corresponds to the common use, in many modern Latin languages, of the word “Pino” to generally mean any pointed conifer⁸⁶. It seems, however, unlikely that Nassarre referred to some kind of proper Pine, as this wood is not found in soundboards and as the second term he adds, “avete”, probably a misspelling of the word “abete”, won’t then make any sense.

Abete is specific and excludes Larches and real Pines; still it can be applied both to Firs, the real members of the genus *Abies*, and also often to Spruces, members of the genus *Picea*. There is a tendency to designate the latter adding some adjectives, like “Abete rojo/ Abete rosso” (es. / it.) or “Abete falso – falso Abete” (es. / it.) in case their proper name “*Picea - Peccio*” (es. / it.) are not used; but this is not general, so confusion may often arise.

There are cases, where no further indications are given, because it is clear, which tree one means, since the others are scarcely present or not found at all: so when one hears of “Abete” in the Italian speaking Alps, excepting Christmas trees, it almost always means Spruce. This is because Spruces represent the overwhelming majority⁸⁷ of all trees, and Firs have almost no economical relevance.

In other regions the opposite may be true: for example in the Iberian peninsula Spruces are not naturally present at all. Firs, on the contrary, although not one of the most common species, are present with two varieties: *Abies Alba* in the north (especially in the Pyrenees) and *Abies Pinsapo* (Spanish Fir), which is present in the very south of Andalusia and in the mountains of Morocco. Even if we cannot be certain that Nassarre used “pino avete” to refer to some kind of imported Spruce⁸⁸, it seems frankly more likely that he was meaning Fir.

84 Nassarre, *Escuela*, 472.

85 Bernard Brauchli, *The Clavichord* (Cambridge, 1998), 128.

86 Larch, Pine, Fir and Spruce look kind of similar and in the spoken language, when no precise classification is needed, can all be referred to with the word *Pino*.

87 In my region, Südtirol, which is located roughly in the center of the Alps and is also partly Italian speaking, that's perfectly true: Spruces are 60% of all (!) trees and Firs are 20 times more rare, building up only 3% of the total.

88 Imported wood is an interesting topic: it seems that Spain started to import lumber from American colonies already in the sixteenth century. One of the most widely used exotic wood in Spanish harpsichords was Cedar; but it appears to have been used only as veneer for the inside of the instrument and not for the soundboard itself.

3. Instruments as source of information

3.1 General discussion on the importance of historical instruments

Several thousands of keyboard instruments survived from historical times to the present day: being more than simple curiosity objects, they represent indeed an invaluable source of information on many aspects of their times. Of all instruments, due to their prestige and mechanical complexity, keyboard instruments hold a special place in embodying their respective Era. In fact at least four different fields can be listed, where keyboard instruments can provide us important information about the past:

-Technology: there has been a slow but constant change from the late Middle Ages to the present day in handcrafting methods, materials transportation, woodworking tools, metallurgical processes and so on. Instruments are silent testimonials of these changes and researchers can read them from a number of signs.⁸⁹

-Decorations: instruments bear clear signs of the ancients' taste for decorations and aesthetics. Each period had its own rules, of course and more or less skilled artisans; nevertheless finishings, moldings, *intarsias*, paintings, outer cases, stands and so on, give us clear indications of what was the taste of the past Eras and how it changed.

-Architecture: instruments often embody the architectonic rules of their time; this applies most obviously to organ cases, but proportional thinking and symmetries found in stringed keyboard instruments also belong to this field.

-Sound aesthetic: this is the most important point from a musical perspective. Unquestionably, the scope of a musical instrument is its sound. Great instrument builders like Pisarenis, Schnitger, Stradivari, Trost, or Stein were genius enough to understand the musical aesthetic of their time and to translate it in terms of sound.

The drawback of this intriguing complexity is that instruments are typically overlooked by scholars of technology, design, architecture and music and since it's hard for one single person to be expert in all of these subjects, many aspects are still only partially understood. Old masters were often at one time organ, harpsichord and clavichord builders, while today players, scholars and builders of each type of keyboard instrument do not know or care enough about the others: this is a curse especially when it comes to understand design and building processes.

My modest research topic, however, has no claim to explain all of these fields and the only question I'm now going to ask the surviving historical instruments of the past is about which material their soundboard is made of. This gives also the limits of my investigation: I'm going to consider clavichords and harpsichords in all of their forms, but no fortepianos⁹⁰, and the chronological period is limited from the beginning of the sixteenth to the end of the eighteenth century.

89 When speaking of musical instruments I categorically refuse to use the word "evolution". I would be less than open if I would not admit that for me the history of keyboard instruments represents very much an involution, where the Renaissance organs, clavichords and harpsichords represent the golden Age. I don't claim any objectivity for my opinion, yet the reader must be aware of my point of view, to judge my work more objectively.

90 Forte pianos and square pianos represented only a small portion of the total instrument's output until the end of the eighteenth century; in this time they also adhered closely to the harpsichord and clavichord making principles. There is therefore no need to include them in this study, as they are not to be expected to add significant information.

3.2 Limitations of modern instrument descriptions

When I first started my project, I had a clear statistical approach in my mind: I wanted to look to as many museum catalogs as possible to make a database of the wood used in different regions. Fortunately GOArt's library had already a dozen of them: I was sure that with enough catalogs it would not have been difficult to make a reliable survey over all of Europe. One does not have to check all of the instruments preserved to gain statistically relevant information, just as election exit-polls do not involve asking the whole population. I started my database in an Excel table dividing the instruments by their present location and listing them using only five fields: type of instrument (harpsichord, clavichord, virginal...); maker; country and city of origin; date of building; soundboard wood type. In a couple of weeks I already had some 300 entries, but I soon encountered the first problems: aside with the fact that almost one fourth of the descriptions provided no indications on the material used, nearly all of the other, except Italian instruments, listed "Spruce."

I was surprised to discover that many organological texts listed a lot of more or less useless details about keyboards and decorations, instead of going into details of the soundboard, that from my point of view, is the most important part of the instrument; I was also confused by the suspicious ubiquity of Spruce. In the same time, in fact, I was collecting quotations from historical treaties and several authors, especially Germans, clearly stated their preference for Fir; some of them went as far as to describe the actual tree, removing every doubt on terminology. Still nearly no trace of the use of this wood was to be found in the catalogs. Eventually I realized that I had to inquire the way catalogs were made in order to understand if their identifications were reliable.⁹¹

3.3 On the identification of wood

As soon as I began to question the reliability of catalogs' information, I started to read about wood identification and eventually bought some Fir planks in order to better understand this material and its difference from the more common Spruce. Cypress, Maple and most other wood types are rather easy to distinguish from each other just by bare eye, but when it comes to Spruce and Fir it is much harder, as they look tremendously similar.

I first asked experienced workers in the sawmill and my kind organ builder, who always helps me with wood: their way of distinguishing the two material is quick and practical, as it relies on smelling.⁹² Fresh cut Spruce has a feeble but pleasant rosin fragrance, while Fir has a stronger and rather unpleasant, ammonia-like smell: since different organisms produce different molecules during their lives and smells are nothing else than chemicals, there is indeed nothing more reliable and practical than using the nose to distinguish wood. The sad point is that it applies only to fresh cut wood, while soundboards typically have been prepared several centuries ago and have since then lost any aroma. Sawing an old soundboard is clearly not an option.

Experienced woodworkers and books agree that the two woods typically have a slightly different appearance, which makes it possible to distinguish them even without smell. Fir tends to be slightly more yellowish in color, sometimes with small purplish effects, while Spruce tends to be

91 Apparently in the more recent catalogs generally more care is given to the reliability of this data. This in turn unfortunately means that several modern catalogs and books, to avoid both wrong identifications and complex investigations, simply list soundboard material as "coniferous wood", "deal" or "probably spruce". This does not really make things easier in my work.

92 It is worth noting that coniferous' rosins have very peculiar smells and that with some experience one can learn how to distinguish Pine from Spruce, Larch, Lebanon Cedar or Cypress easily just by nose. Fir does not have rosin, but retains still a very peculiar smell when fresh.

lighter and possesses a slightly different shine. Annular rings are typically slightly more sharply defined on Spruces with a more marked transition between springwood and latewood. Sometimes Fir presents more irregular annular rings and the portion of latewood is bigger than in Spruce; yet it is not always the case and none of all this visual evidence is very strong. If one compares freshly planed surfaces, they may actually be distinguishable. When it comes to soundboards, however, whose wood has been darkened by sunlight, chemicals in the air and dirt for centuries, no reliable visual comparison is possible anymore. Some instruments in addition to natural aging, also had some kind of surface treatment on the soundboard (varnish or grounding for paintings), which clearly does not make things easier.

The two kinds of wood generally have different typical defects, that helps identifying them in a reliable way: Spruce has dark brown knots, which tend to separate rather easily and it also has sometimes pitch-pockets and rosin deposits, which are never found in Firs as their wood does not contain rosin at all. These latter, instead, split more easily, tend to have somewhat less sharply defined knots and the area around the pith tends to be wet; this often leads to the fact that while drying out, the annular rings around the core shrink more than the rest and so eventually split from the surrounding ones. Unfortunately for our research, but luckily for the quality of the instruments, any self-respecting builder would do his best to not incorporate defects like knots, rosin deposits or the pith region in his soundboards, so no comparison on this basis can really be made.⁹³

This long discussion is just to say that after some practical woodworking experience, I would feel comfortable to distinguish Fir from Spruce in a workshop, where you can examine a bigger plank typically with knots and, if needed, you can plane it down to discover its color or saw to smell its fragrance. I would however not entrust myself on a 300-years-old dusty soundboard. So I have reasons to doubt that the average catalog curators, many of whom have never had direct practical experience, are to be trusted when they make identifications just by eye.

The only affordable tools seem to be hand lenses or microscopes. This, however, implies a certain degree of skills and knowledge about specific wood's micro-structure and is best carried out by experts. As the soundboard is typically dirty, this method also implies that at the very least one has to scrape the surface in some spot or even to plane down the end-grain, which reveals clearly the wood structure. End-grain can be reached only at the belly rail, as it is normally covered by moldings elsewhere; it is possible, but strings on the clavichord, and wrestplank and registers on the harpsichord, may make the operation difficult, as they are in the way. The other method is to take a small sample of material to a laboratory, which in most cases, except during restorations, is not really an option.

Finally I don't want to blame anybody's work, but I think there is reason to question how deeply catalog curators have been willing to go into wood identification matters. Keeping this in mind it is indeed not surprising that catalogs made using the most reliable wood identification techniques show a much broader variety of species, while those who did not even bother to specify the method used (which leaves us in doubt on their accuracy), typically list "Spruce" for everything but Italian instruments.⁹⁴

Since traveling around the world to examine each historical instrument with a lens is not an option for me, I will sketch a very approximate atlas of wood use in different European countries on the basis of sources and information that I was able to collect at the present state of research.⁹⁵

93 Some pitch-pockets are however found on Rucker's harpsichords, well hidden by paintings.

94 One of the most accurate is *Keyboard Musical Instruments in the Museum of Fine Arts, Boston* by John Koster, Boston, 1994. The author expressly states that microscopic investigations have been carried out and in fact among the identifications an otherwise uncommon soundboard "biodiversity" is present.

95 For more details about different European building schools, see Hubbard, op. cit., Kottick, op. cit and Brauchli, op. cit. For detailed information about individual builders, see Donald Howard Boalch, *Makers of the harpsichord and clavichord 1440-1840* (Oxford: Oxford University Press, 1995).

3.5 Tentative atlas of wood used for soundboards in Europe

-Sweden

If most early instrument builders were of German origin, from around the second half of the eighteenth century several local building traditions flourished in Sweden. The most prolific maker was Pehr Lindholm, working in Stockholm. Almost all instruments produced in Sweden were clavichords: they tended to be very big compared to other European traditions, often with a large compass and mostly unfretted. Soundboards were of **Spruce** and typically had the grain direction angled to the spine. The source of soundboard material was almost certainly local as it is widely grained, not always regular and generally not of an impressive quality.⁹⁶ These characteristics are most likely due to the effect that the extremely wet Swedish climate has on Spruce growth and can be commonly observed on today's commercial lumber.

-England

From the end of the seventeenth century a local building tradition flourished especially in London. The most famous makers were Burkat Shudi and Jakob and Abraham Kirckman. The surviving instruments are mostly harpsichords and spinets, with a few, older, virginals and virtually no clavichords. Luckily the Boston Museum of Fine Arts, whose catalog was made using the most accurate system of identification, possesses one instrument each for Shudi and Kirckman: both instruments have a **Spruce** soundboard. Also Stephen Keene, who worked in London, between the end of the seventeenth and the beginning of the eighteenth century seems to have used the same wood. These masters may well be considered representative for their production and for that of their colleagues, as they were all working in the same city. It is hard to say where their wood came from, but it is not unlikely that it was imported, as Spruce is not naturally present in England.

-Low Countries

Instrument building has a long tradition in Flanders: the earliest surviving instruments date from the middle of the sixteenth century. The Golden Age started at the end of that century with the rise of the Ruckers Family in Antwerpen, which can probably be regarded as the most influential dynasty in the harpsichord's history. Among the instruments that survived there are harpsichords, virginals, some combination of two instruments sharing the same case and a few clavichords. The Ruckers' practice was also taken as a paradigm by their later followers, without radical departure from their basic features. They used **Spruce** in their soundboards, which indeed corresponds to what written sources suggest.⁹⁷ It seems probable, as historical authors report, that wood came to the Low Countries from Switzerland through the Rhein *Flößerei*. Yet some authors suggest the possibility that Spruce could have been imported from the Baltic area, particularly around Danzig, since importing wood from this area to Antwerp is documented.⁹⁸

96 The fact that for modern, visual-based, standard the wood quality of Lindholm's soundboards is not as high as one would expect, does not mean that his instruments do not sound well. Indeed some aspect of the soundboard construction peculiar to Swedish instruments, like the angled grain, might have been intentionally thought-out to cope with the lack of regular and fine grained spruce.

97 Grant O'Brien, *Ruckers: A Harpsichord and Virginal Building Tradition* (Cambridge: Cambridge University Press, 2008), 100.

98 Grant O'Brien, *Ruckers*, 73.

-German-speaking Countries

It is extremely difficult to draw some reliable conclusions on the wood usage in Germany, because historically it used to be divided into a number of more or less independent regions. In organ building this led to the development of several different schools and it is presumable that the situation of stringed keyboard instruments was similar. However the fact that the largest part of the surviving instruments are unpretentious clavichords, which hardly bear a date or name, does not make regional attributions easy. The other, already mentioned problem is that it is difficult to establish how far the present wood identifications are reliable, as they do not agree with written sources. This attempt to give indications on the wood used in German countries is therefore highly speculative and the division into macro-regional building schools may appear to be partly arbitrary.

North Germany has had a long history in instrument building, its main center being the city of Hamburg. Its importance is nowadays more linked to seventeenth century organs than to stringed keyboards, perhaps due to the fact that few instruments survive from this period. From the beginning of the eighteenth century, however, several preserved harpsichords and clavichords can be attributed to North German builders. In this context a special place must be reserved for the instruments of Hieronimus and Johann Hass, which due to the lavish decoration, refined sound and uncommon technical solutions, represent a highpoint in that building school. Luckily a separate study on their clavichords is available: the author was open enough to admit that only visual identification was carried out.⁹⁹ Indeed since he was able to discover pitch-pockets on the underside of some soundboards during restoration, there was no actual need to carry out more specific tests. In fact the only wood that matches the visual appearance of the soundboard and presence of pitch-pockets is **Spruce**. Where this wood originally came from is, however, hard to say with certainty.

Central Germany, especially Saxony and Thuringia, seems to have had a rather autonomous building tradition, yet attributions are particularly problematic for this area. Indeed most of the written sources come from this area and they all agree on the use of **Fir**, which also commonly grows there. Still there is almost no trace of this wood in catalogs. Again, the Boston catalog with its reliable identifications, despite housing only some 15 instruments, delivers some small surprise: one clavichord made in Dresden by J. G. Horn's heirs has a Fir soundboard. Yet only one instrument is not enough to draw statistically reliable conclusions: we are left with the suspicion that many "Spruce" soundboards listed in catalogs are indeed made out of Fir, but without any certainty.¹⁰⁰

South Germany, Switzerland and Austria represent another building tradition; these countries were never politically unified, yet the common environment of the Alps surprisingly generates more affinities than human borders may suggest. The tradition in instrument building is extremely old: indeed the Viennese physician Hermann Poll is credited to have invented the harpsichord at the end of the fourteenth century.¹⁰¹ Few big names, however, are to be found until the rise of the Viennese piano tradition. The Alps are also virtually the only part of the world where good soundboard wood is always on sale, as **Spruce** builds up roughly half of the total trees growing there and the climate is ideal. With such an abundance it is not difficult to find the characteristics one wishes: slow grown, stable wood with narrow annular rings, few nodes and straight grain is surprisingly easy and cheap to get.¹⁰² This explains why builders from this area preferred using Spruce. Fir is also present in the Alps, but its quality is generally so poor that it is used only for packaging; other conifers like Pine or Larch, were never used in soundboards.

99 Lancelot Edwin Whitehead, *The clavichords of Hieronimus and Johann Hass*, (Ph.D. diss., University of Edinburgh, 1994).

100 A notable exception is the harpsichord by Hans Müller made 1537 in Leipzig: it has a cypress soundboard.

101 Kottick, *A History*, 10.

102 This fact did not escape some talented luthiers: Antonio Stradivari, based in Cremona, used to get his soundboard wood from the forest of Paneveggio, located in the Val di Fiemme, in the Italian part of Tirol. Jacob Stainer, the great master of the German building tradition, worked and got his Spruce just some 150 km north.

-France

France seems to have had two different Eras in keyboard instruments building: the early phase, when a more native building tradition existed and a later phase, roughly from the beginning of the eighteenth century, when the Ruckers' influence started to rule the craft. Since between these two periods many characteristics of the instruments changed and since the earliest phase appears to have been much less standardized, it is indeed possible that Mersenne's indications about Cypress and Cedar soundboards reflect actual practices. We will probably never know, as only few preserved French instruments date from before 1700 but for the later phase we have reliable data. The big center of keyboard instrument making was the city of Paris and the most renowned makers, the Blanchets and their follower Pascal Taskin, were appointed royal harpsichord makers. Since a considerable part of the work in those days was the *ravalement* of older Ruckers harpsichords, whose soundboards were considered especially valuable and often reused in new instruments, we can also rightfully argue that information on Flemish practices have relevance for France as well: both tradition used **Spruce**. Some other French makers, however, also used **Fir** for their soundboards, as we can see for example in instruments by Henri Hemsch.

-Italian States

If one takes a closer look at Italian culture, one must admit that the concept of Italy as a unity was for centuries nothing more than a fiction carried on by men of letters, as regional and municipal traditions still are very strong now and were much stronger in the past. If municipalism, however, is a curse when it comes to giving unitary political organization to a country of 60 million people, it was also a real blessing as an engine of cultural production. During the past millennium each city and court was competing to get the most beautiful art treasures.

Nature changes very rapidly through the Italian peninsula: it ranges from a warm and dry subtropical climate in the south, to a continental one in the north or even to a sub-arctic climate in the highest alpine districts. This dramatic range makes clear that in different regions very different tree species were available. Here I'll try to summarize some important building traditions, without any claim to be exhaustive, as no specific studies have been published on the different regional Italian schools.¹⁰³

Venice was one of the wealthiest cities in the world during the sixteenth century: at that time it was one of the most important centers for music and music publishing as well as the main center of keyboard making. Many instruments have survived in good condition, despite their extreme age: they are mainly virginals and harpsichords, but also a few clavichords can be linked to Venetian makers. The more important ones are Vito Trasuntino and Dominicus Pisarenus at the beginning of the century, Giovanni Baffo and Giovanni Celestini towards the end. Venetian instruments represent nowadays a major part of the whole surviving body of Renaissance stringed keyboards. They typically were designed for longer iron scales, but were mostly later modified for shorter brass scaling; four foot registers and the C-f^{'''} compass were very common. **Cypress** was used in those times for casework, soundboard and bridge. Several of them, especially virginals, were carried out with extremely lavish decorations. Later instruments used Spruce soundboards as well.

The region of **Lombardy** was also an important center of instrument making during the Renaissance. Several fine virginals survive from Annibale Rossi (active in Milan) and Gian Francesco Antegnati¹⁰⁴ (Brescia). They show some affinities with the Venetian school, yet a closer

103 Much of the information here is taken from Denzil Wraight, op. cit., from articles on the author's website and private correspondence.

104 Gian Francesco was the brother of the famous organ builder Gian Giacomo Antegnati. He was organist at San Giuseppe, regularly helped his brother and had his own workshop in Brescia. He also worked on (repaired?) some virginals by the Venetian master Marco Jadra.

look reveals many features that make the production of these builders unique. Both masters used **Cypress** in their soundboards.

Florence was an important harpsichord and virginal building center from the beginning of the sixteenth century. Instruments from this period often show split sharps and it seems that this particular feature was very appreciated in central Italy during the early seventeenth century.¹⁰⁵ At the end of the century Bartolomeo Cristofori, with his extremely clever and personal technical solutions, had a long lasting influence in instrument building not only in Italy. Cristofori and his forerunners mostly preferred **Cypress**, but **Spruce** and **Fir** were also used.

It is difficult to overstate the musical importance of the city of **Rome** in the Baroque period: the names of Frescobaldi, Rossi and Pasquini speak for themselves. It is obvious that such an active artistic environment sought for fine keyboard instruments. The most prominent makers were: Boni, active at the beginning of the seventeenth century, who also made many instruments with split sharps; Zenti, the genial builder who traveled through whole Europe¹⁰⁶ and is accredited to have invented the bentside spinet; and Giusti, whose instruments have become through the many copies, a sort of paradigm of “the” Italian harpsichord for modern builders. Their instruments have a **Spruce** or **Fir** soundboard more often than **Cypress**.

Naples and southern Italy had again a completely different tradition from the rest of Italy and many details in layout, scaling and construction differ. There is a nucleus of sixteenth century instruments thought to be of Neapolitan origin scattered through the world's museums: among them several wing-shaped harpsichords and the two oldest clavichords, called “Leipzig n. 2 and 3”. Honofrio Guarracino is regarded as the most important maker of the seventeenth century; of the instruments made before his time, very few are signed and this long made attributions to this building school problematic. Recent studies of constructional details and old measurement systems have brought, in the last decades, a better picture of the Neapolitan school.¹⁰⁷ **Maple** was widely used for casework and it was also used in the soundboard of some of the earliest harpsichords. This is a feature unique to Naples. However, both in this city, and in Sicily, the other major center of production in southern Italy, **Fir** and sometimes **Spruce** were regularly employed.

-Iberian peninsula

Even considering Spain and Portugal as a whole, very few harpsichords and clavichords survive from the area and are nearly all from the eighteenth century. Apparently they also failed to attract the attention of scholars, as extremely little has been written on Iberian instruments. It has often been noticed that extant Harpsichords in their appearance resemble Italian instruments; still similarities in most cases only apply to the outside and not to the construction. Examined more closely, these instruments seem to embody two different influences: the Italian and a more international one. This fact is also reflected in the soundboard materials: some instruments have a Cypress soundboard, some others show one that may be of either Fir or Spruce. Historical sources are of little help in this regard: the only one I know of speaks of *abete*, which is a term that applies to both trees. Until more material on Iberian instruments is published, we are left in the dark.

105 Denzil Wraight, *A list of surviving Italian string keyboard instruments originally provided with more than 12 notes per octave* (2010). Published online on <http://www.denzilwraight.com/download.htm> .

106 Zenti was in Stockholm at the service of Queen Christina of Sweden shortly before she converted to Catholicism and moved to Rome. He also seems to have worked in France and England. Anyway, even if he was regarded as one of the best makers of its time, he was only paid about the half of musicians.

107 A detailed description of the features of the Neapolitan building school can be found on Grant O'Brien website, <http://www.claviantica.com>

3.5 Natural distribution and characteristics

-Spruce (*Picea Abies*)

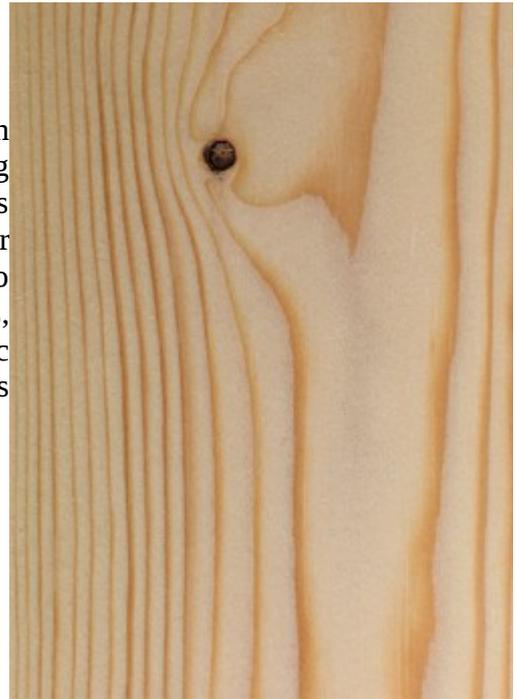
Spruce is a large and fast-growing evergreen coniferous tree, which usually grows 35-55 m tall, reaching a trunk diameter of 1 to 1,5 m. Its wood is soft and has normally a fine, even texture, and straight grain. Annular rings are evident and the transition from springwood to latewood is mostly sharp defined. These characteristics, however, can vary noticeably depending on the climatic conditions. It is rather easy to work with, as long as no knots are present.¹⁰⁸

Average Dried Weight: 405 kg/m³

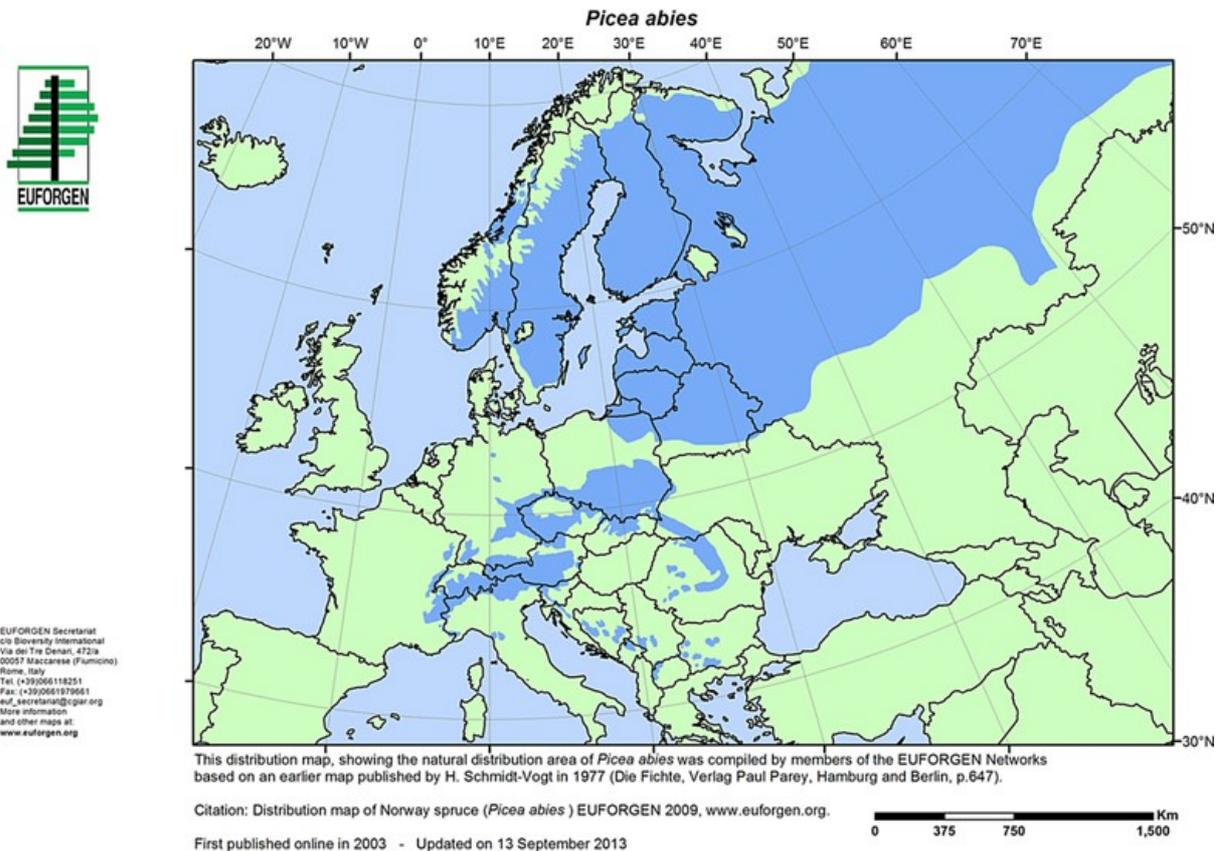
Modulus of Rupture: 63.0 MPa

Elastic Modulus: 9.70 GPa

Shrinkage: Radial 3.9%, Tangential 8.2%, Volumetric 12.1%



Natural range:



108 Most of the information is taken from: <http://www.wood-database.com/> and <http://www.promolegno.com>.

-Fir
(*Abies Alba*)

Fir is a large evergreen coniferous tree that can grow to 30-46 m reaching a trunk diameter of 1-1,5 m. Its wood is soft with straight grain and a uniform, medium-coarse texture. Resin and resin canals are absent and the transition from earlywood to latewood tends to be more gradual than in Spruce. These features, however, depend once again greatly on the habitat. In Andalusia and Sicily two subspecies of Fir exist. It is generally easy to work with, but it tends to split easily.



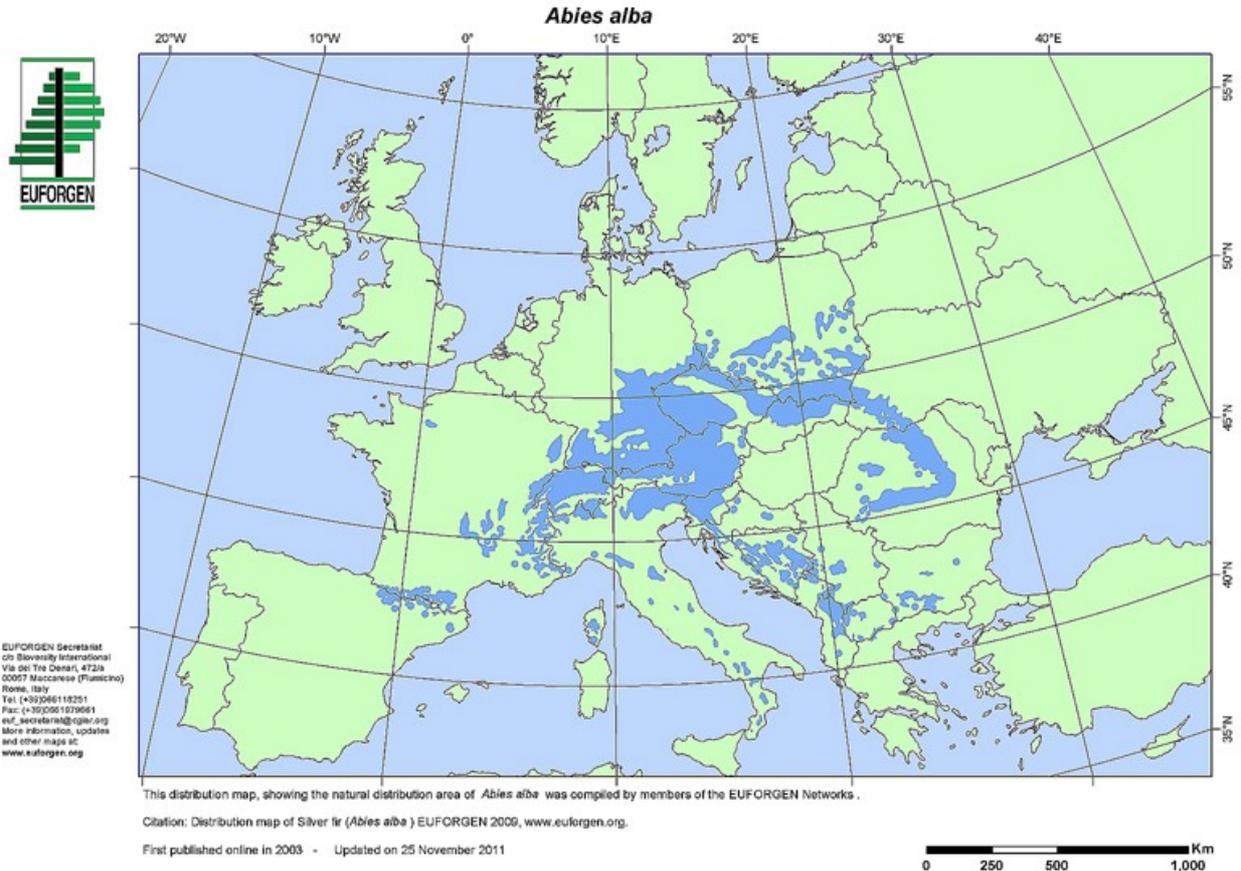
Average Dried Weight: 415 kg/mc

Modulus of Rupture: 66.1 MPa

Elastic Modulus: 8.28 GPa

Shrinkage: Radial 4.0%, Tangential 8.7%, Volumetric 12.8%

Natural range:



-Cypress
(*Cupressus Sempervirens*)

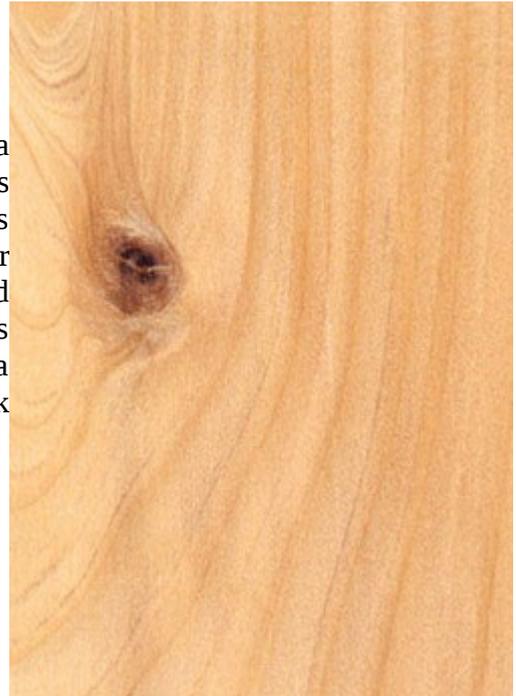
Cypress is a medium evergreen coniferous tree with a characteristic conic crown. It can live very long and becomes 20-30 m tall with a trunk diameter of 60-100 cm. Its wood is medium-hard and has a fine texture with sometimes irregular grain, due to frequent presence of knots. Annular rings tend to be irregular; the transition from springwood to latewood is gradual. It is durable to insect attacks, rot and has a characteristic fragrance. It is not always easy to work because of knots and wild grain.

Average Dried Weight: 535 kg/mc

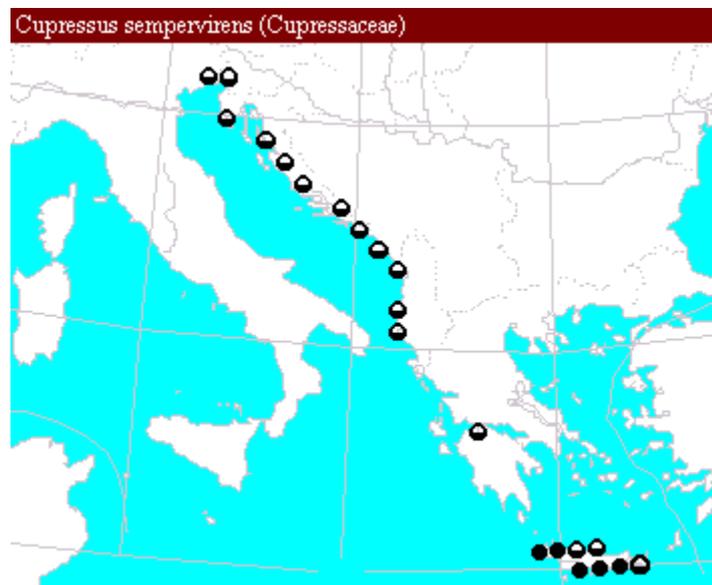
Modulus of Rupture: 44.6 MPa

Elastic Modulus: 5.28 GPa

Shrinkage¹⁰⁹: Radial 3.0%, Tangential 6.0%, Volumetric: 8.6%



Natural Range¹¹⁰:



109 Data for this particular species of cypress are not available. Since I think the particularly low retirement of cypresses may indeed be important to understand their employment, I made a mean using the data of all other natural (not artificial hybrids) varieties of the genus *Cupressus* present in the database to give at least an indicative value to compare with other listed lumber. I tend to think that this may indeed be representative, as retirement values are fairly consistent for all species of cypress.

110 This chart is taken from <http://www.conifers.org>. It refers to the natural range of cypress, which is the eastern part of the Mediterranean region; but the plant has been widespread by man as ornamental tree already in antique times and can now be found, both cultivated and naturalized, over the whole Mediterranean area. It is interesting to note that all regions belonging to the natural range of Cypress were once part, or had important economical exchanges, with the Republic of Venice.

-Maple (Sycamore)
(Acer Pseudoplatanus)

Maple is a large deciduous tree that can become 25-35 m tall, with a trunk diameter of 1-1.2 m. Its wood is hard, has a fine even texture and, depending on the specimen, its grain can sometimes be wavy. Sycamore Maple can also be found with curly or quilted grain patterns, which are particularly sought-after for veneering and violin bottom boards. Unless irregular grain direction is present, its workability is good.



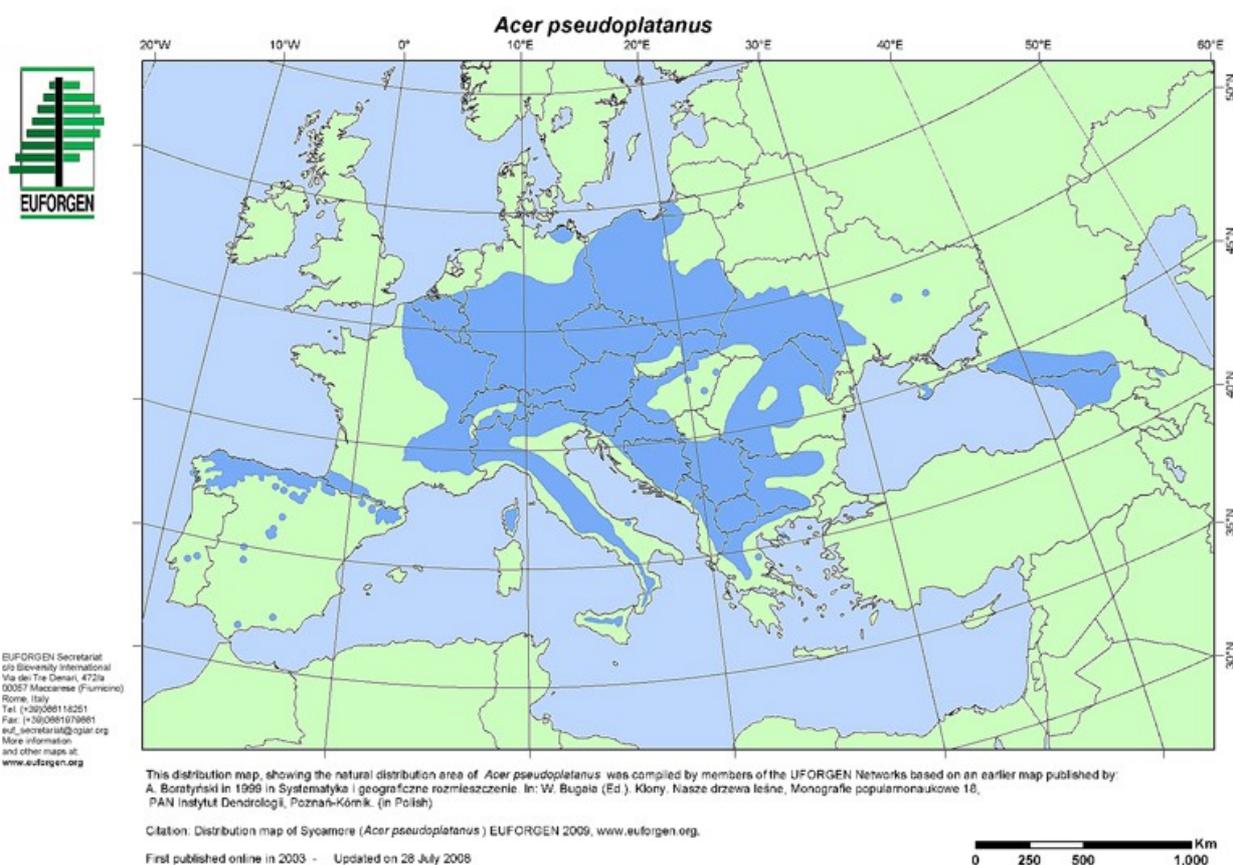
Average Dried Weight: 615 kg/m³

Modulus of Rupture: 98.1 MPa

Elastic Modulus: 9.92 GPa

Shrinkage: Radial 4.5%, Tangential 7.8%, Volumetric 12.3%

Natural range:



4. Genesis of an experimental instrument

4.1 Traveling ideas

I am one of those boring persons that still has not bothered to buy a smart-phone. So every time I had to travel by bus last year, from the island of Björkö to Göteborg's center, I could not listen to music, play games, watch movies or write messages. Given the fact that talking to strangers seems not to be an option in Sweden, the only interesting things I had with me were some books and my brain. The Brain also has its own rules: it needs sometimes to relax, sometimes to focus on specific matters and I can bet that in the next decades new studies will appear on the fact that our mind actually needs those “dead” times that smart-phones so hardly try to destroy. Also in life there are periods of excitement and delusion; the most intense brain activity coincides at least for me with the first ones. So it was indeed fortunate that when I first came here, full of dreams I also had so much time to think, because now, having little time and expectations left, I won't be able to find a similarly clever solution to the technical problems that this work implies.

When I first started to think about the present project, I did not want to limit myself to some more or less interesting research on sources, but I wanted an acoustical practical response. The workshop is indeed for me a more stimulating environment than a library, therefore I wanted to build real instruments, employing the material we were to discuss in theory. The initial project involved the ingenuous idea of making four different small clavichords following exactly the same plan, but using different materials. This had many advantages in my eyes: firstly I could spend very much time in the workshop making new interesting building experiences, secondly I then would have four small, nice instruments, which I could use both for the comparison and for my own playing pleasure.

I thought the idea was good and I started to talk about it to a leading American harpsichord builder, Keith Hill, who is always very kind, as he replies quickly and likes to talk about building matters. His kindness also relies on the fact that he always says openly whatever he thinks and expresses himself in a rather colorful way. So his comment on my project was that it was just worthless, because in comparing different instrument you actually have no constant. At first I felt demoralized, but I had to admit his objection made sense: to compare just the soundboard, the rest of the instrument should stay the same. Fortunately in that dynamic period my imagination brought me to a new, challenging idea in just a few days: a clavichord with an interchangeable soundboard.

This is, as far as I know, something which has never been tried before. And indeed, although the concept may appear simple, many technical problems had to be solved. Clavichords tend to be simple in their mechanism and have few parts just like two-stroke engines: the typical drawback in such systems is that a small change on one part will have major influences on the other. So the design had to be very well thought-out before coming to a realizable project.



4.2 Design matters

In a normal instrument (harpsichord, virginal or clavichord) the soundboard rests under the strings and is glued to the liners, which are in turn glued to walls and bottom. There is no way to get the board out without having to remove all of the strings and ungluing it. If animal glue is used, as in historical times, it is still somehow possible to remove it, but it is a very delicate operation and the risk of damage is high: it is considered the very last resort in restorations. For my purpose repeating the tests on a single conventional clavichord regluing the soundboard each time has several disadvantages: first you obviously have to remove strings and re-string the instrument again several times; not only is it a long, painstaking process and it may progressively wear out holes in the wrestplank, but strings also need some time to adapt to tension, typically improving the sound after the first weeks.

Second, one may likely not be able to repeat the tests again, as soundboards may get destroyed during the removing operation.

Third, a new bridge is needed for each soundboard; its shape is difficult to copy reliably and small differences in its shape, position and in the placing of pins surely can affect the results.

It was soon clear that the only way to make a clavichord with a removable soundboard is to avoid gluing it to the liners, making it possible to extract from the underside. A part of the bottom should be removable and liners should serve to clamp the soundboard against a stop which can determine the level of the soundboard from the top.



Since the bottom is perhaps the most important structural element in a conventional clavichord, removing a piece of it with the strings in place would make the instrument virtually implode due to tension. It is hard for people to imagine how much tension there can be on an apparently small instrument like a clavichord, so it is worth mentioning that the structure has to withstand a total force that ranges from 250 to 700 kg or even more. This also makes clear why virtually all historical clavichords are warped and why one has to be very careful in making part of the bottom not contribute to the instrument stability. Typically the bottom's function is to keep the instrument flat: since in most clavichords the stringband is angled to the spine, there is a clear tendency of the back-left and front-right corners to bend inwards.¹¹¹ It is clear that a conventional

111 Some historical makers, like Christian Gottlob Hubert, also tried to angle the bottom's grain in the same direction as the string, to make it more tension resistant.

angled stringband would not be usable in connection with a removable soundboard as it would result in a structural fail since part of the bottom support is missing. The only way is to make the stringband parallel to the case, as in Renaissance clavichords, so that spine and walls would support tension almost by themselves. The other important aspects are to give the frame a generous thickness and to keep the total tension low.¹¹²



With parallel stringbands another scenario becomes possible: since the strings are held in place from hitch- and wrestpins, no bridge pins are needed; in fact Renaissance clavichords do not have them: instead of relying on the side-bearing with angled strings and tuning pins to couple strings to the soundboard, they rely on down-bearing with either a sloping soundboard or down-pressure bars.¹¹³ It is therefore no longer necessary to drill pin holes and this in turn eliminates the risks of slightly misplacing them, which may affect the acoustical result. In this arrangement, commonly found on Renaissance clavichords, it is also not mandatory to glue the bridge because, with no lateral forces, the string pressure alone ensures a tight fit, as happens on violins. This in turn makes it possible to use the very same bridge in all tests, as it can just be detached or applied on top of each soundboard.

112 Indeed the frame thicknesses I used (12mm for walls and 16 for the spine), do not depart much from historical models using the northern, on-the-bottom, construction. A relatively low total tension on the structure was not achieved by tuning strings too far from their breaking point, as this would spoil the sound, but by the combination of small compass and fretting. This allowed to build a full instrument with only 24 pairs of strings.

113 We started with a bare wood bridge with no down-pressing bar. As I had no previous experience with this kind of arrangement, I believed that the down-bearing from the bridge to the tuning pins would be enough to ensure coupling between strings and bridge and efficiently transfer vibrations. The problem was that it sounded too dull and that the vibrations, were transferring through the bridge to the strings' after-length; also while playing fortissimo the top strings could be lifted from the bridge. So we first inserted a string in a groove on the top of the bridge, as in some Renaissance clavichords, and this made the instrument sound a lot more clear and brilliant; some months later we provided it with a down-pressure bar which is angled in a similar direction as the bridge. This made the sound more solid and focused and solved the problem of strings lifting.

Making the bridge straight and of a triangular shape is the easiest thing when it comes to making it easily reproducible and there are indeed several historical models of straight bridges, however they were mainly used in very small instruments. As for its orientation it was a little more complex to decide: straight bridges either were angled but had pins and angled strings; or they were perpendicular to the stringband carrying part of the strings.¹¹⁴ This last forms with partial bridges was typical for the sixteenth century and implied having 3-4 straight bridges for treble, tenor and bass range. I could not escape the impression that in this arrangement, lacking a coupling between the different parts of the bridge, the soundboard might work in a slightly different way; indeed some of the oldest clavichords with multiple bridges have also the soundboard made of different pieces, while in none of the later instruments, with a single bridge, this is the case. So for all of these reasons I chose to try an “intermediate” solution, not found in historical clavichords, having a single, straight, 45° angled bridge, without pins. This allowed me to use a suitable keyboard compass at roughly normal pitch and scaling, while keeping foreshortening and keylevers' cranking in the bass to decent levels.

The final choice was for a compass of 38 keys, (F,G,A-g",a") which was common during the Renaissance and allows the playing of some literature and to test different pitch regions. The scaling was intended for iron strings at high *Chorton* (a' at ca. 495hz) with an f' of 192mm (c" = 256 mm); the transition to brass strings at f° was helpful to keep the foreshortening in the bass to acceptable levels.

I think that this brief description gives general readers a good picture of the basic problems that the special construction of this clavichord involves, while not overwhelming them with too specific details. For those readers who wish to go even deeper in following the development stages of this instrument, I enclosed in **Appendix One** a private mail to my professor, where I explained all the options I had been considering, and I gave him justifications of my final choices about scaling and layout.¹¹⁵ **Appendix Two** is about scaling, stringing, fretting and string tensions.

4.3 Designing methods

In those first months I came to Göteborg, a new world opened up to me: for the first time in my life there were people around me with deep knowledge about historical instruments and I was finally able to consult a huge library. I never experienced anything like this before and probably, given GOArt's present situation, it won't possible for others to experience the same in future. I started reading articles about ancient units of measurement and simple proportions and I immediately became an enthusiast of the practical advantages of this approach.¹¹⁶ The basic assumption of this theory is that historical harpsichords and clavichords were designed and marked out using measurements: therefore the dimensions of important parts of the instrument should correspond to simple numbers in the local units of measurement. I found this approach interesting: proportions are indeed vital in instrument making but working with modern metrical units does not make things easier in this regard. Most people would not immediately visualize that 1320mm and 440mm long boards are in a proportion of 3 to 1, but if one establishes that the unit of measurement is an inch of 22 mm, they easily become self-evident, as 60 and 20 inches, clearly being 3 to 1. The

114 Having one single straight bridge perpendicular to the stringband is the third option and means having strings of equal length. The only means to make them sound higher or lower is to work with fretting and keylever cranking, diameters and tension. This system was used in the fourteenth century and may work on high-pitched instruments, as we can see on Praetorius' image of the *octav clavichordium* (pg. 20). For normal-pitched clavichords it is extremely unfavorable, as the bass strings will necessarily be too foreshortened and keylever too cranked.

115 The text is left as it was originally written, without any editing. It explains at length, in a vital but chaotic way, several important stages of this planning phase, which I briefly reported here. It also obviously reminds of the good old days, when my English was terrible and I was trying to address everybody in German.

116 Grant O'Brien has devoted much of his work in explaining instrument's design and manufacturing process using ancient local units of measurement. Several articles on this subject and analysis of actual instruments' design are kindly made available on his website: www.claviantica.com.

same is valid for subdivisions: that's why I eventually considered it profitable to establish my own working "inch" of 24 mm, which I baptized "*Gargazoner Zoll*" from the name of my home-village: 24 is in fact perfectly divisible for 1, 2, 3, 4, 6, 8, 12 and itself. This means one does not have to build any special measuring devices and can still use rulers marked in mm, since conversions to this 24mm inch typically involve basic mathematics on integer numbers. The other advantage I discovered in practice, is that this system, rationalizes wood usage: left over pieces re-sawn to thicknesses which are fractions of the same inch, are very likely to be useful again.

Finally, a GOArt researcher and my advisor suggested me to read an article about geometrical construction, which was based on Anton Walter's fortepianos.¹¹⁷ The basic assumption of this theory is that most part of the instrument are not measured at all, but they are derived by geometrical means from a basic measurement, that corresponds to a vital aspect of the design (for example keyboard or stringband width). This second method of construction is also very efficient, because one does not have to deal with drawings and frequent measurements: the instrument layout just takes place on the bottom board with straight edge, square and compass. This piece is then used as reference for all the rest. This system is fast, precise and secure against errors: since successive dimensions are found by geometrical means just working with a compass, errors tend to correct themselves; if the basic measurement is a bit smaller than it should be, everything else will be proportionally smaller with no practical consequences.

In those times I was still not aware that scholars advocating for the geometrical-proportional design and those advocating for the use of simple geometry and local units of measurement were strenuously arguing against each other.¹¹⁸ I just considered the advantages of both systems and accidentally mixed them in my clavichord, as one approach does not practically exclude the other. Since I had to build the instrument in less than one month, during the Christmas vacation, it was worth trying these unconventional approaches together. In the end of November 2013, I laid out on paper the new instrument using the stringband width (6 *Gargazoner Zoll*) as a basic unit; the diagonal of its square ($\sqrt{2}$) and the golden section (φ) to find all other dimensions.¹¹⁹ I will stop my written description here, because nobody will understand the layout of this clavichord just by my words. I will enclose, instead, as **Appendix Three** a plan of the instrument.



117 Stephen Birkett and William Jurgenson, *Geometrical Methods in Stringed Keyboard Instrument Design and Construction*. The article is to be found on jw.zabernet.de/bill.2014/pdfs/fpdesign.pdf

118 Describing in depth both approaches and how they work in practice is far beyond the scope of the present work and would require a whole separate volume. I gave the general reader a general idea of their basic principles and invite him to look at the plan of my instrument: construction lines around the stringband explain how the outer dimensions of the case were found.

119 The keyboard is apart, as its basic unit is given by the width of its plank, divided into the number of natural keys: this gives the key width. The sharps are half this width and their lateral disposition is found with the compass.

APPENDIX ONE: (communication on design matters)¹²⁰

Dear Joel,

I noticed today that every time we see us I come up with very strange Ideas and projects. I don't want to give you the impression that I'm completely superficial in what I'm doing [...]

it's a long time that I'm thinking about the project of the clavichord with removable soundboard. Today I told you only some ideas, which may point to a superficial approach but indeed I have already thought about a lot of possibilities. Since it's not easy to explain everything by talking, I'll try to describe some of the backgrounds idea here.

Why an instrument with F,G,A-g',a" compass? First: I regard instruments as uninteresting as long as you can not really play something on them. It seems obvious. But it's hard to judge the overall result from single notes such as it was on the examples of the "Tibia Clausa". Second: I think one of the most instinctive thing to check the sound of an instrument is to sit at the keyboard and play some chords. "Strangely enough" there seems to be some correspondence in the literature with pieces which begins with simple or arpeggiato chords from Cavazzoni to Mendelssohn (later I simply don't care).

I would not regard satisfying to have an instrument which cannot play normal 4 parts chords. Moreover i can figure out that some changing in the soundboard and bridge will affect more a region than another. So we either build different instruments for Bass region, Tenor region and Soprano or we build an instrument that roughly can cover them all. F to f" that is 35 keys only allows you to play few early works. With F-a" you can play or adapt a big amount of music from the sixteenth century up to Frescobaldi's polyphonic works and even some toccatas from the first book. I think for an experimental instrument that's ideal: you don't have the problem of the massive foreshortening of low C, still you can play "real" music.

Making it double fretted in the common diatonic way it would require some 24 pairs of strings (i.e. F,G,A,B,H,c+cis,d,es+e,f+fis,g+gis,a,b+h,c'+cis',d',es'+e',f'+fis',g'+gis',a',b'+h',c''+cis'',d'',es''+e'',f''+fis'',g''+a''). We could even make it more compact building it triple and quadruple fretted in the treble as probably older F-a" instruments were. But I wonder if that's necessary: making a sinful scaling with a straight bridge is difficult itself: with the problem of multiple fretting it may become even worse. More over, marking out a double fretted system on a ¼ comma meantune is quite easy, because all of the frettings are diatonic semitones. Making it unfretted would mean that we could also experiment with the bridge curve shape... I mean: at least as long as the structure does not collapse on itself, since we will miss the structural supporto of the piece of baseboard directly under the soundboard (it will be only screwed on). We could make 2cm thick oak walls to partially prevent that. Or we could just make it fretted.

Why to make a straight bridge? That's easy: you told it today: making a something different shape of the Gerstenberg bridge greatly changed the sound. Giving that curved bridges are hard to make perfectly of the same shape and they are very time consuming. Making a straight bridge has none of these disadvantages. We could even think of making a "moulding plane" especially for making bridges of exactly the same profile. But maybe it's not necessary.

What about scaling and bridge orientation? Yes, all bridges from extant instruments with a compass similar to which one I am planing, seems to have straight partial bridges. I know. But most of the instrument in which we are interested in, excepting the Pisarenis, does not have this feature. They have S, inverted J or angled straight bridges.

The problem of the bridge is that it determines by a big amount the string length. By thinking about the scaling I begun to think about the stringband as a trapezium. If the string are 90° or not it does not matter: the lowest string (longest side) is almost parallel to the highest one. The other two end are given by the tangents and by the bridge. The problem starts in the tangents: however one can build cranked keylevels up to 3-4 cm or more, this is useless to compensate bigger differences. So the actual octave span has also an indirect effect on the string length. This means if we would build the lower keys 8 time as wide as the top one, we would be right and could have straight levels. Since keys are (unfortunately) all of the same with, we have problems and we have to choose.

Phytagorean scale: most of the small clavichords did not follow a straight phytagorean scale. So what? Since the following of the phytagorean principle has major effects on tone quality, I see that probably the best thing to do is to depart gradually from that, having the smoothest foreshortening possible, possibly avoiding breaks. Why? Because when we will be judging the result of our work I would like to be quite sure that a certain note or region sounds brilliant or dull because of our work and not because there is a sudden change in the scale. Possibly for a skilled builder it was possible to mask small differences in the scale, because they new how to make a sound beautiful. Since I'm only trying to discover that, I would be glad to start with the simplest means possible.

120 Since this was a private and spontaneous communication to my teacher and is here intended to be a document of the designing process, it is left as it was. No editing and corrections to the original have been made.

Since I decided to use my new “inch” of 24mm, which will allow me to make practical subdivisions and easy to see proportions, I have made several hypothesis about the strings lenghts. I think it is a good practice to think about the f-notes lenght. At least it seems that very old, especially italian instrumets were f" based. Since this instrument is practically F to f" plus a third, it is even more convenient:

Inches	5	5,5	6	6,5	7	7,5	8	8,5	9
f"	120	132	144	156	168	180	192	204	216
f	240	264	288	312	336	360	384	408	432
f°	480	528	576	624	672	720	768	816	864
F	960	1056	1152	1248	1344	1440	1536	1632	1728
c" equiv.	160	176	192	208	224	240	256	272	288

Of course we will have to foreshorten the bass, but the esigence of not having too cranked levels, giving an octave span of 168 (7 inches) can give us some practical ideas on how to make the bridge work.

Multiple straight bridges: this is the hardcore way of the good old times, no question. Anyway this is a very peculiar construction with unglued bridges (this by the way is going to give us a lot to think about building our Pisaensis), thick ribs running under sloping soundboards. I wonder if the results achieved for making a such clavichord sound good could be easily used to make a Friederici work well. It goes with itself that notion like the driving point and the tuning of the bridge ends of the soundboards have to be radically rethought. More over it brings with itself another problem about scaling: the gaps. We probably will use even different materials like Iron, brass and red brass. Unless we use iron for the bass, the change of material will make the gaps even worse. Think of a c' of some 400 mm in iron and a h° some 100mm further away in brass. This means a ratio of 400 to 600mm; a whole quint instead of major third gived by the bigger space alone. I cannot figure out how to make them sound equal... one will be necessarily dull or the other will break.

Straight single bridge: with a straight bridge the only factor which increases string lenghts is the octave span and the keylevel cranking. This practically means you choose a lenght for f" and then you can just add the octave span for every other f note. I have already made calculations in the Röd express a couple of days ago:

	string lenght: diff. to phytag:		string lenght: diff. to phytag:		string lenght: diff. to phytag:	
octave span:		144		132		120
f"	0	144	0	132	0	120
f	168	312	24	300	36	288
f°	336	480	-96	468	-60	456
F	504	648	-504	636	-420	624

Having a single straight bridge may work, as you can see, only for very small instrument (c" 192-160 or less) without having too much cranked levels and or too much foreshortening. Some very smart scholar may be able to bring this in connection with the very first clavichords of the fifteenth century, which seemed to have had one bridge and infact shor scales, high pitch and a smaller compass. Since I'm not so smart and I would like to play an instrument at roughly normal pitch (which for me means a' around 465 Hz! :-p) to play chords and hear real “Basses”. I would rather choose an angled bridge.

Angled bridges: yes, that's not so unusual fo a clavichord to have a single bridge (or at least a sction of) roughly angled from 15° to 60° to the bellyrail. Virtually every clavichord except the five or six dating back to the renaissance have that. So maybe it's the most representative solution for making experiments on bridges and soundboards. We can choose very easily the angle; maybe we can find a good convection for accurately locate bridges on further soundboards we are goind to make. And, yes, it probably helps with foreshortening and level cranking with longer scales. In case of an angled bridge, the change of material in the strings rather than beeing a disadvantage, becomes a resource. We can have longer sopranos in order to have less cranked tenors, which can be strung in brass and basses that can be of red brass. The ration between iron and brass is 6 to 5 with red brass beeing even more far apart, so we can already calculate that with a foreshortening of some 20% we will still be within phytagorean scaling. We actually don't even have to be so regretfull to Phytagoras; but probably we don't even want fo have basses which sounds like crap.

I made calculations even for this. I took as example a bridge angled at 45° to the strings. This means that the space between the pairs of strings in the stringband is equal to the increase of their lenght. So when we have the space between from f" and f strings, which for a division of 6mm (¼ inch) for each pair in a double fretted system is 42mm, we know that the string lenght, without regarding level cranking is going to be the actual octave span (168mm) plus that. So every octave is going to improve by 210mm. That is 0 at f" and 210, 420 and 630 respectively at f f° and F.

One can just add the initial f" lenght and have an idea of the foreshortening.

	string length:	diff. to phytag:									
octave span:	144		156		168		180		192		
f [#]	0	144	0	156	0	168	0	180	0	192	0
f	210	354	66	366	54	378	42	390	30	402	18
f ^b	420	564	-12	576	-48	588	-84	600	-120	612	-156
F	630	774	-378	786	-462	798	-546	810	-630	822	-714

I think we should not try to have an actual F to f[#] ratio of less than 50%. Otherwise we will probably end with an instrument with poor and dull bass region. I mean: we could easily do if we'd have to make a small instrument to carry around. But since we are making an instrument to experiment sound it should plan it to have a good sound consistently over the whole compass.

Straight or angled stringband? That's a complicated question: if we look at the early clavichords they had strings parallel to the spine. But since we've not always looked at early clavichords for laying out this instrument, why should we do it now? Indeed every instrument from the 1620 onwards has an angled stringband. As have that of Praetorius. However the very first had a very small angle; and the instrument of 1620 in Edinburgh has still all of the hitchpins on the left side, which points to a very gentle angle, if any. But I've never seen a plan view of that. If one postulates that evolution in musical instruments is gradual, there may have been also instruments with straight strings and angled bridge at the end of the sixteenth century. Anyway: why to discuss about this and not to make a very normal angled stringband? I see some advantages in having a straight stringband: first you don't need to have bridge pins to hold string in place, as there is virtually no side pressure, being the string on a straight line from the hitch pin to the wrestpin. Probably even if you have an angled bridge, if the downpressure (i.e. the bridge height) is enough, you probably don't need bridge pins, which in turn means you don't have to mark them out and accurately drill them to have a new bridge and a new soundboard. The only thing which can exert some sidepressure on the strings is the tangent itself, but most of its movement is directed vertically. Maybe if you have a sufficiently pointed bridge, the strings themselves will cut a little groove in which they will eventually rest such as it normally happens in violins. So probably we'll not have problems with angled bridge and straight stringband. And just in case we discover we have a problem after we finished, we can still remove the soundboard and drill holes for pins. So I don't think that's a vital point and it's maybe worth trying without pins first.

Another advantage of making the stringband parallel to the spine is the fact that then the frame alone will be able to hold the string tension without significantly warp. 48 strings are not many, but owing that a part of the baseboard will be missing, it is probably wise to remain on the safe side. With a protruding keyboard design, the frame will be sufficiently narrow (under 300 mm) to be stable. If we joint in even the wrestpland and bellyrail, we probably can achieve a very good strength even without the baseboard support over the whole length. The other option is to have the baseboard in one piece but removable. This means it will give more strength when it is on. But the whole structure will be very stressed when we'll be about to change the soundboard, because there will not be any baseboard at all. I've made a similar experiment, because I had a too thin baseboard (I wanted it to act as second soundboard) on my first instrument (which was single strung) and when I could notice by eye that the structure had significantly warped while tuning it one half-tone higher I decided that it was time to install a new baseboard. But changing it with the strings on, even if I loosened the strings a lot (I could not loose them totally because the wrestpins did not have any hole) was not really easy/pleasant. If we can manage to have a robust structure with only an opening for changing the soundboard it's better. The tangent will be more wide apart if we have a straight stringband, so that the F tangent will be much more close to the balance pin than that of the a[#]. Anyway, since the stringband itself will be some 144 mm (24*6mm) we have plenty of space between the two walls to make a decent level ratio. I think we probably better make also an angled balance rail. It does not have to follow exactly the same level ratio for the whole compass, but to correct it a little it's probably not a bad idea. We can even decide to make a straight rack as Leipzig 2 and 3, if the strings are going to be hitched all on the left side. [...]

So, to conclude: in the design there are probably a lot of other things, which play a role. But from an acoustical point of view I think the most important factor in design is the pitch and the string scale. That's what we have to do first. If we want to choose Iron as material and we tune it a tone higher than today with g[#] at 440, then we probably have to stay something around 256mm or more for c[#]; if we choose my beloved pitch with g[#] at 440 we'll have to stay around 272mm. We can even choose a scale and then decide at which pitch it sounds best, but anyway according to that scale, we should choose a bridge angle and then maybe we can correct inbetween by cranking the levels. But that's only a guess. I don't know what the best way to design a such instrument, I'm only trying to figure out the best order. When we have the scale I can start with the rest of the design...

So, good night! Have a nice weekend! Fabio

**APPENDIX TWO:
(stringing and tensions)**

Note	Frequency	Phitag.	Ratio Ph.	Zoll	Length	Frets	String D.	Tension	Tens. Diff.	Ratio to f2
gis'	460,00	192,0								
F	98,44	1536,0	0,547	35,00	840	Rot	52	5,19		0,68
G	110,06	1314,8	0,613	33,58	806		48	5,09	-0,10	
A	123,05	1228,8	0,630	32,25	774	Mess	44	4,93	-0,16	
B	131,66	1148,4	0,660	31,58	758		44	5,27	0,34	
H	137,57	1099,1	0,673	30,83	740		44	5,48	0,21	
c0	147,20	1027,2	0,701	30,00	720		40	4,91	-0,57	0,84
cis0	153,81	983,0		0,00		689,04		4,91		
d0	164,57	918,7	0,731	28,00	672		40	5,35	0,44	
es0	176,09	858,7	0,764	27,33	656		36	4,73	-0,62	
e0	184,00	821,7		0,00		627,79		4,73		
f0	196,88	768,0	0,797	25,50	612		36	5,14	0,42	0,96
fis0	205,72	735,0		0,00		585,68		5,14		
g0	220,12	686,9	0,827	23,67	568	Eisen	36	5,04	-0,10	
gis0	230,00	657,4		0,00		543,58		5,04		
a0	246,10	614,4	0,856	21,92	526		36	5,40	0,36	
b0	263,32	574,2	0,888	21,25	510		33	4,88	-0,52	
h0	275,14	549,5		0,00		488,07		4,88		
c1	294,40	513,6	0,917	19,63	471		33	5,21	0,32	0,92
cis1	307,62	491,5		0,00		450,75		5,21		
d1	329,15	459,4	0,947	18,13	435		33	5,55	0,34	
es1	352,18	429,3	0,978	17,50	420		30	4,90	-0,65	
e1	368,00	410,9		0,00		401,94		4,90		
f1	393,75	384,0	1,000	16,00	384		30	5,12	0,22	1,00
fis1	411,44	367,5		0,00		367,49		5,12		
g1	440,23	343,5	0,999	14,29	343		30	5,10	-0,01	
gis1	460,00	328,7		0,00		328,25		5,10		
a1	492,19	307,2	0,999	12,79	307		30	5,11	0,01	
b1	526,64	287,1	1,000	11,96	287		30	5,11	0,00	
h1	550,29	274,8		0,00		274,66		5,11		
c2	588,80	256,8	1,001	10,71	257		30	5,13	0,01	1,00
cis2	615,24	245,8		0,00		245,95		5,13		
d2	658,30	229,7	1,001	9,58	230		30	5,13	0,01	
es2	704,37	214,7	1,002	8,96	215		30	5,13	0,00	
e2	736,00	205,4		0,00		205,76		5,13		
f2	787,51	192,0	1,000	8,00	192		30	5,12	-0,02	1,00
fis2	822,87	183,7		0,00		183,74		5,12		
g2	880,46	171,7	0,990	7,08	170		30	5,01	-0,10	
a2	920,00	164,3		0,00		152,05		5,01		

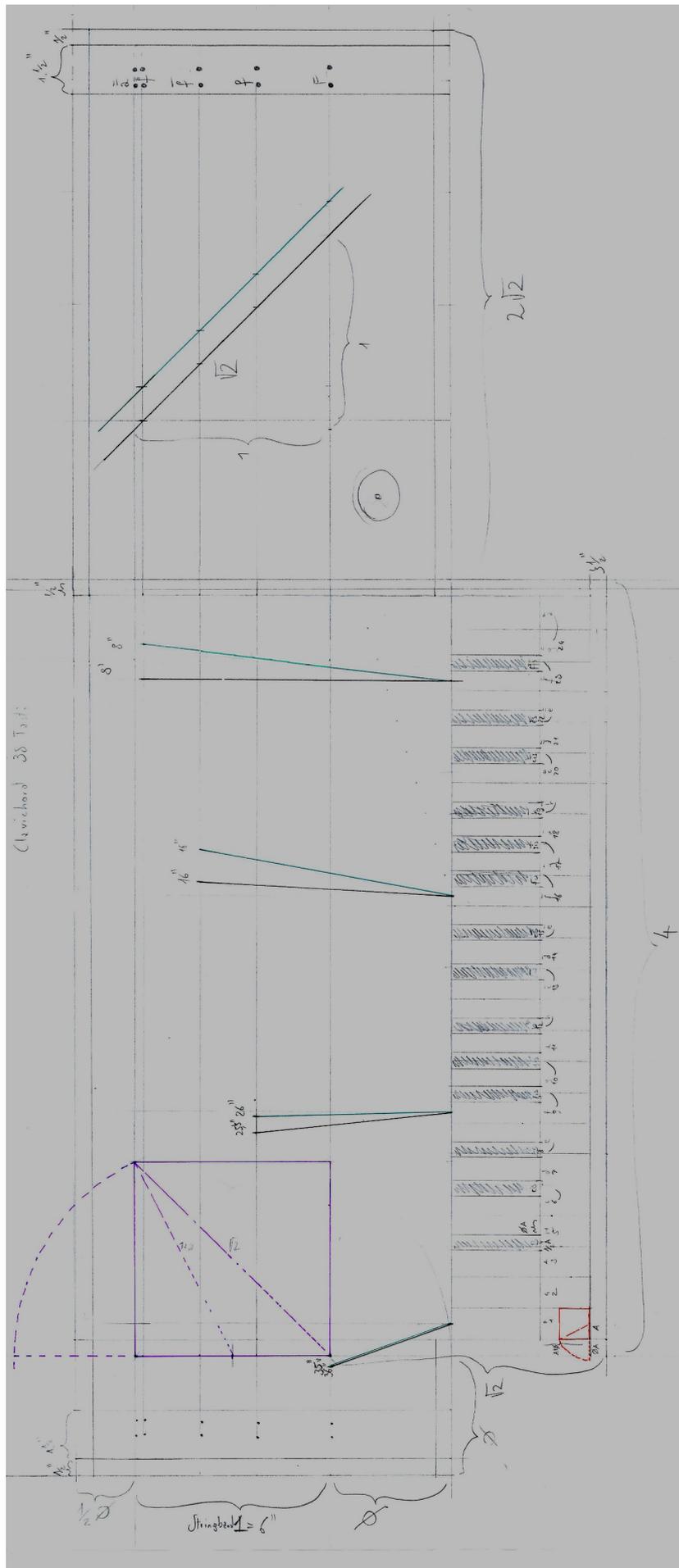
Total: 246,09

Average: 5,13

Explanation of the table:

Note is corresponding key. **Frequency** is the note's frequency in Hz. Calculations are made for ¼ comma meantone. **Phitag.** is the theoretical string length if it were inversely proportional to the frequency. As one can see, the starting note is f2 with 192mm and the length doubles at each octave. **Ratio Ph.** is the ratio between the actual and theoretical length. **Zoll** is the actual string length expressed in *Gargazoner Zoll* (24 mm). **Length** is the actual string length chosen. **Frets** is the string length of the fretted notes. It is calculated for the chromatic semitone in meantone (0,957). **String D.** is the wire diameter expressed in hundreds of mm. **Tension** is the calculated tension of the strings when tuned to the target frequency. **Tens. Diff.** Is the difference in tension between successive notes. It is useful for deciding where to change wire diameter ant to avoid sudden changes in keyboard touch. **Ratio to f2** is the ratio between the actual string length and its theoretical value (as in Ratio Ph.) taking in account the different string materials. Since brass strings requires a shorter scaling than iron ones, the typical ratio of 6/5 between them is used.

**APPENDIX
THREE:
(plan view of the
instrument)**



5. Measurements and recordings

5.1 On the soundboard samples

We chose to carry out tests for each of the different wood types I was able to individuate in sources and extant instruments. This is in detail all the information I was able to get on this wood:

Spruce: I sliced 3 samples from a short but thick piece I had at home. The wood is straight-, regular- and rather close-grained, quarter-sawn and was laying in my workshop since June 2013. I personally acquired it in a sawmill in Val di Fiemme.

Fir: I sliced 3 samples from a piece I selected from a larger board. The wood is straight-, not particularly regular- and rather close-grained. It is quarter-sawn and I bought in a sawmill from South-Tyrol in June 2014.¹²¹

Cypress: I sliced 2 samples of different width from a thick, 90 cm long piece and I then cut them to half. The wood is straight-, but, as usual for Cypress, not so regular- and not so close-grained. It is close to quarter-sawn. I bought this wood from an Italian supplier in August 2013, hoping to make a copy of the Pisarenis' clavichord. I don't know further details about its provenance.

Maple: I had a suitable long but thin piece in the workshop, from which I was able to cut 3 subsequent boards. The wood is rather straight, not so regular and not close-grained, which is precisely what one expects from hardwood of this kind. It is quarter-sawn. I bought this wood in December 2013 to build the experimental clavichord of this project. Also the bridge and case of the instrument is made out of this wood. I don't know any details about its provenance.

As for preparing them, I first planed flat one surface and its edge with the jointer, then I used my bandsaw to slice roughly 5mm thick boards and finally I used the thicknesser with the same setting to plane the other surface and give all pieces a similar thickness.¹²² All pieces of the same wood come from the very same tree.

5.2 On the set up

From the beginning on, I planned to carry out tests on the soundboard material, to have a better picture of their physical properties. As I'm no scientist and I won't pretend to be one, I needed somebody to help me in conceiving and carrying out the tests, as well as in getting access to the necessary equipment. It was not easy at the beginning, but I finally found in Carl-Johan Bergsten a kind partner, who made these tests possible.¹²³ It is not always simple to measure physical properties of materials in a quick and rapid way and it was also only possible to prepare samples in my workshop at home, where I had access to the right machinery and materials. So we decided to limit ourself to the actual pieces of wood that we were going to turn into soundboards as we could not

121 As it was partly fresh, I had to season it on my own; unfortunately the weather was not so favorable. I suspect that the humidity content of the samples was still a bit high.

122 This happened in august 2014; unfortunately, because of the big change in humidity conditions, from an extraordinary wet summer to an extremely dry Scandinavian indoor environment, some sample pieces slightly warped and moved (especially Fir). This explains why the dimensions measured are not exactly the same, even if they were planed in a row with the same machine. For practical purposes, since variations were quite small, it was possible, cutting edges away, to glue pieces up into fairly flat and even soundboards.

123 Carl-Johan Bergsten is research engineer at GOArt, the organ research center of the Gothenburg University.

produce a large number of samples. Before carrying out the tests I also used a small bandsaw with a fence to give all pieces the same width. For the present tests it was not necessary to give all pieces the same length, so I chose to leave them over-sized to make further soundboard preparation easier. We decided to measure four parameters:

- physical dimensions** as length, width, thickness, volume
- weight**, in order to get relevant parameters like specific weight and weight to stiffness ratio
- bending** under load, to gain information on material stiffness
- vibration decay**, in order to have a visual representation of the material's inherent damping

We marked each sample with a number and used an electronic caliper and a simple ruler for measuring dimensions. Wood is a lively material, that slightly but constantly changes its shape and dimensions; also the machinery I used to prepare samples has its own tolerances. Therefore I chose to measure length on both ends of the pieces, while width and thickness, in addition, were also measured in the center. I then made a mean of each of these values to calculate the volume of the pieces.

For weighing I first tried to use a normal digital balance, commonly used for weighing letters, which had a resolution of one gram. Since, as one would expect, the weight of similar pieces of wood is very consistent, I felt compelled to make measurements with better accuracy, to measure even the small variations that naturally occur between pieces of the same wood. Indeed using a balance with an accuracy of one decigram (0,1g) already shows that none of the pieces, even coming from the very same tree, is really alike. After calculating the specific weight of each sample, it is possible to notice how the range of variations within the same type of wood is still rather limited compared to the differences between different types.¹²⁴ Values of these two measurements are found in **Appendix one**.

Finally I made a support on which to clamp samples in the same position and we used a laser displacement to measure how much boards would bend, loaded with the same amount of weight (a cylinder of 400 g placed at exactly 280mm from the clamping point). In this system the variation in the distance from the laser was reflected in different voltages: we registered the starting voltage and the “loaded” point with a tester. Since the difference between the two voltages was the only thing that mattered, small misplacements in the sample clamping or slightly curved surface were of no consequence, as they were already “included” in the first value. Measurements of this type were repeated only once, as it turned out that they would give the exact same results if repeated.

We were able to use the same clamping device and laser to measure how quickly vibrations would decay, when the boards were set in motion and let free to vibrate like a reed: this was an attempt to measure the damping that the material has, when set in vibration.¹²⁵ To excite the samples all in a similar way, I made a “C”-shaped wooden block that would lower and hold down the free end of the boards to the same distance from the table; retracting this block would cause the wood pieces to spring back and vibrate for a certain amount of time. While exciting boards in this way, the laser displacement, collected to a laptop was measuring in real time the number and amplitude of vibration cycles for 10 seconds, representing waveforms of the decay on the screen. From this data it was then possible to calculate the material damping. This test was repeated three times in a row for each sample and gave slightly different results each time. The values are, however, likely to be representative as they are consistent for each sample and more generally for each material. In **Appendix two** and **three** pictures of the set up and values of the measurements are to be found.

124 The values measured do not always correspond with the indicative average values given in chapter 3.5. This is not really surprising, as this parameter can vary significantly in wood coming from different habitats and also from tree to tree.

125 On the other side one should not try to set this damping value too close in connection with the decay pattern of a real instruments: on an actual soundboard it depends much on the overall stiffness, which is achieved mainly through appropriate barring and thickening.

5.3 Recordings

After having carried out measurements on the samples it became time for the final stage: that of hearing them. I turned them into soundboards planing their sides in pairs with a hand plane and glued them together with hide glue. Then I removed glue remains with plane and scraper and cut them to the correct size using the removable liners as marking jig. I clamped each soundboard to the free portion of baseboard using their upper left edge as reference to locate them accurately. In the baseboard 2 small holes had already been made to locate the bridge, it was enough to drill through them into the clamped soundboard to have a precise bridge position for all of the samples. Since barring can highly affect the sound and misplacements in bar gluing can happen very easily, I chose to first test the soundboards without any bar at all. Since thickness is also a major parameter, I deliberately avoided doing anything advanced for this first test: after gluing the boards together, I just evened them as flat as possible with a metal hand plane set to a very shallow cut and finished with a scraper: after cutting them to final shape and measuring the thicknesses in several places, each measurement ranged between 3,4 and 3,6 mm.¹²⁶ The bridge itself, being held in place just by two 2 mm dowels inserted in this 2 small holes, was simply applied or detached to each soundboard before inserting it into the instrument. After this, the brass string topping the bridge and the downpressing bar were put back in place.

I was really surprised at how consistent the whole system is: after replacing the soundboard the clavichord was still decently in tune. Since the instrument is pure meantone and double-fretted, the tuning is very easy so I chose to tune the instrument again each time, following the same tuning pattern¹²⁷. I started playing and improvising for a little while to get comfortable with the sound and went on recording first all F and C strings and then the first part of the *Pavana Lachrimae* setting by Jan Pieterszoon Sweelinck two times on each soundboard. I got the best results having my recording device placed directly on the soundboard, near the bass strings in the lower left corner.¹²⁸

The acoustical result of the different soundboards was very similar, as I expected, with some subtle differences in timbre and volume between different wood types. Somehow I got the impression that listening to the instrument while playing, despite the fact that many subjective factors and expectations may play a role in deceiving our perceptions, gives a more objective feedback of the sound. I suspect that for some reason microphones and speakers tend to “color” the sound, so whatever you hear from the same equipment sounds partly alike. I am saying this because the differences in the sound were much more obvious in the “live” playing than on the recording: indeed I was surprised how alike they sounded in playback and I started to recognize the same characteristics I was noticing while playing only focusing carefully on certain passages and using spectrum analysis.

126 One may point out that using a hand plane is not a good choice for a scientific experiment. Indeed also a modern compact thicknessers in my experience won't lead to a better result than this. Probably one would need a professional jointer and thicknesser within a humidity-controlled environment to achieve perfectly similar thicknesses and maintaining them over time. I must admit I'm no scientist, but rather a very practical craftsman: since this equipment was not available neither to me nor in the past, even if I have to partly admit this critic, if the wood choice is to be linked to an acoustical difference, this must have been audible in historical times even without advanced modern machinery.

127 I started silencing the internal strings with a wool cloth and tuning the external pins rows, then I tuned the g'1 accurately to 440. I went on tuning eb' to g' and h' to g' in pure thirds, checking also the fifths eb'-b' and e'-h'; the following steps were: c'-e' checking c'-g', a°-c#° checking a-e', I tuned a' and c'' to a° and c' and went on with f'-a' checking f'-c'' and d'-f#° checking d'-a'. I tuned the rest in octaves and finally removed the wool cloth for tuning the central pins to their unisons. I am referring here to the German note names with the Helmholtz octave indication.

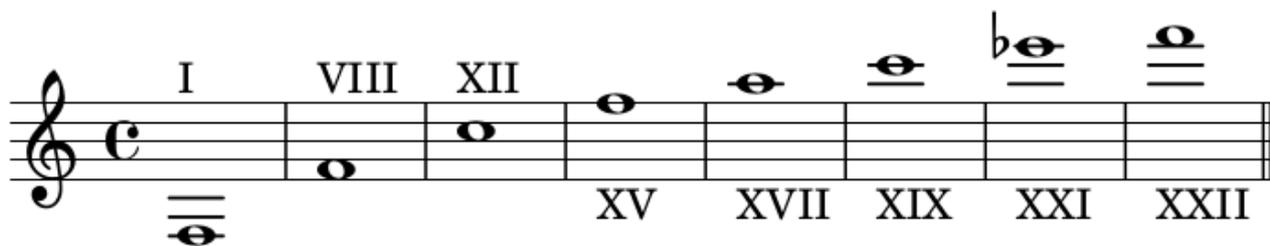
128 It seems that when the temperature in Göteborg approaches 20°C most people start to drive insanely fast and many tuned cars suddenly appear. When this happens, it is very tricky to avoid muffler sound in a clavichord recording, so this recording session was really tiresome.

Another important thing that is not possible to establish from a recording is loudness: of course you can hear if one passage sounds louder on a certain soundboard, but you have no basis to judge, as the clavichord is a dynamically sensitive instrument. When playing, instead, one can control dynamics and immediately recognize if the instrument sounds generally louder than it sounded half an hour before with another soundboard. This is why, even if I generally mistrust subjective opinions, I feel it is important to write my “live” impressions here: I found the Fir soundboard to be the loudest, followed closely by Spruce. The difference between them is that Fir has a little more brilliance and clearness in timbre while Spruce gives a more fundamental and sweet sound. Cypress felt somewhat softer, but I started to notice an interesting and subtly reedy sound, especially in the middle and bass range. Maple was the softest one, giving a thinner sound with less fundamentals compared to Cypress.

If I should express my subjective preferences, I remark that I found the lute-like, powerful but round sound of Spruce to be very pleasant; also the “reedy”, somewhat softer and drier but very clear sound of Cypress is musically very interesting, the Fir sound being perhaps a compromise between these two. I did not find the Maple sound particularly attractive. It is important to remark that I tested them in this order: Fir, Spruce, Cypress and Maple. This probably influenced also the way I experienced them, the most clearly felt difference being that between Spruce and Cypress.

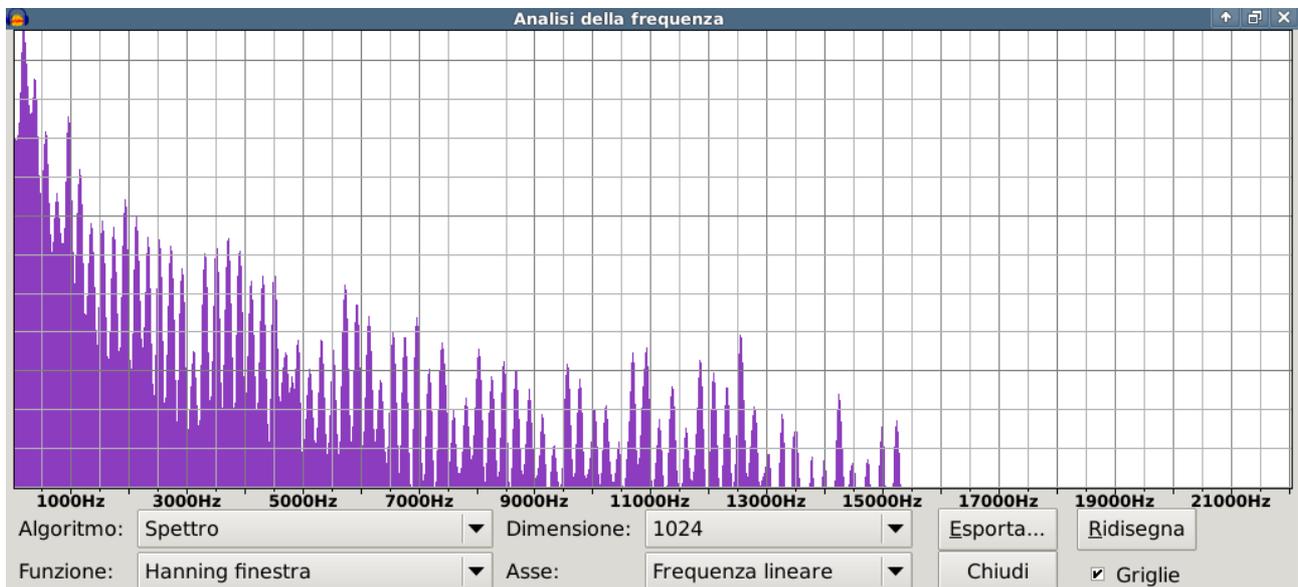
After giving my opinions it is a good counterpoint to show some overtone spectrum graphs: as I recorded all F's and C's, I will here give the analysis of each tenor f (f°). This region of the compass typically sounds particularly good on clavichords as it has a full and rich tone; on this instrument it is also the last note strung in Brass wire. In the analysis I skipped the striking point, that may introduce noises not directly dependent on soundboard and strings, instead I chose to consider the first 0,98 seconds after the loudest point. Analysis on notes played repeatedly on the same soundboard showed that the frequency spectrum is not much dependent on dynamics: peaks corresponding to the overtones produce similar shapes on the same material, which clearly differs from graphs of other materials, whether they are played loudly or not.

Spectrum graphs, as puzzling as they may look at first, are fairly easy to read: each peak corresponds to an harmonic partial, the very first one being the so-called fundamental. Successive partials, called overtones, and correspond to musical intervals to the fundamental.¹²⁹ The second partial (second peak, first overtone) forms an octave with the fundamental; the third partial correspond to the twelfths of the fundamental; the fourth partial to the fifteenth; the fifth to the seventeenth; the sixth to the nineteenth; the seventh to the twenty-first; the eight to the twenty-second. To make it even more clear, the first eight partials (the fundamental plus seven overtones) for tenor F are reported below in musical notation: the first eight peaks in the graph corresponds to these notes.

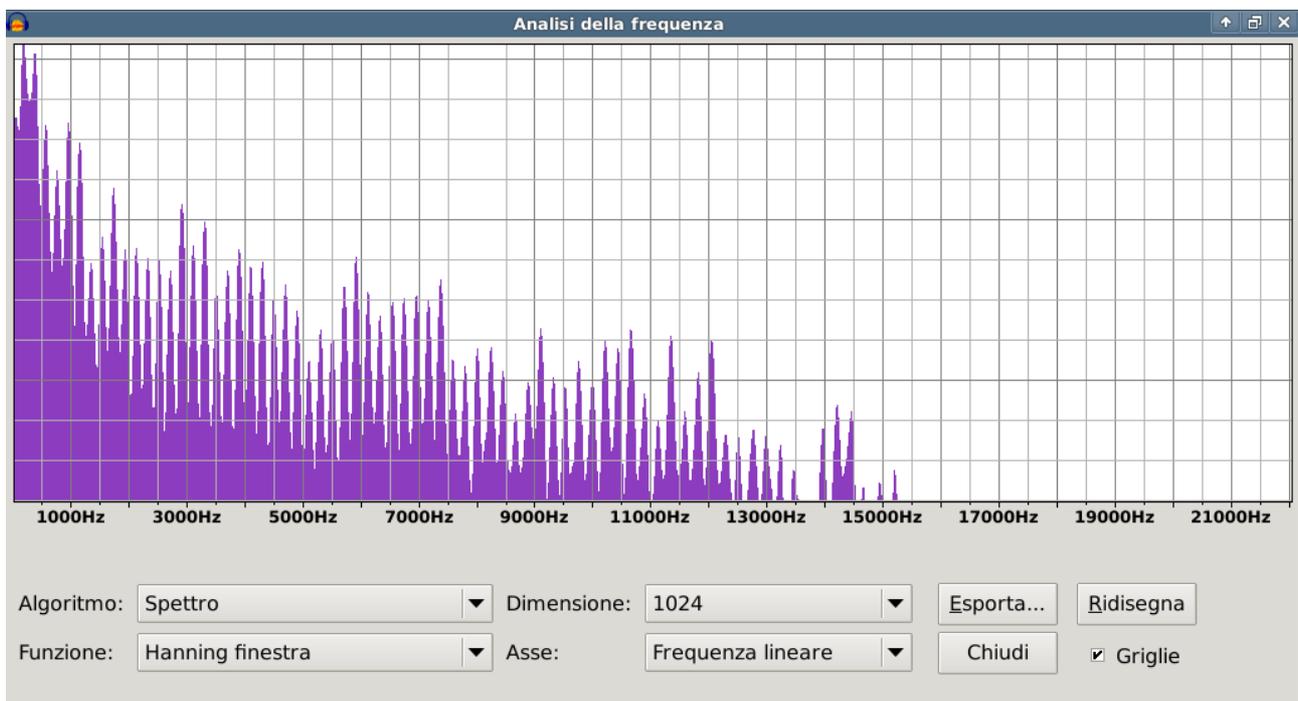


¹²⁹I will here indicate the overtones according to their musical interval to the fundamental. This old practice is commonly used in counterpoint and in the traditional ranks names of the Italian *ripieno*, as well as in English and Spanish organ stops.

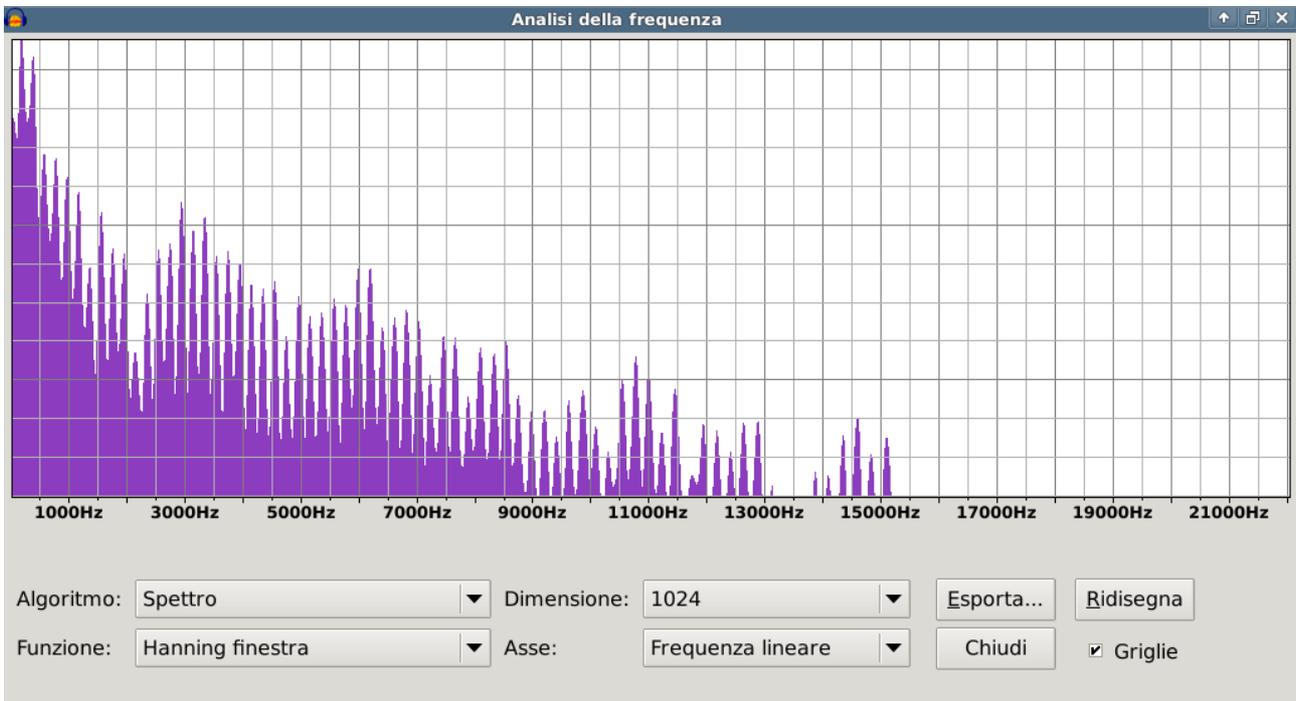
Fir produced a graph without obvious peaks or leaks, except the one around 3000Hz. The octave (corresponding to the second peak in the graph) is not particularly strong, compared to other woods; the other overtones are more or less in the average, except the seventeenth, which is remarkably strong and placed between a weak fifteenth and nineteenth.



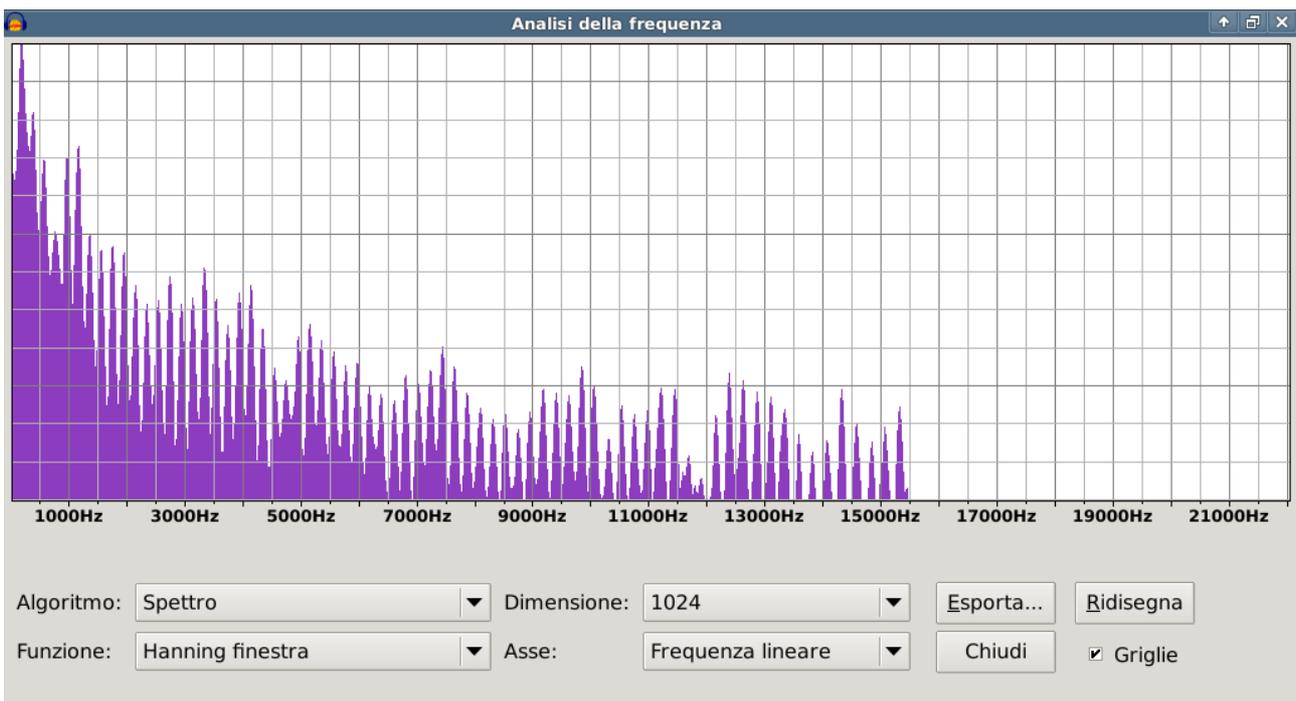
Spruce produced the smoothest graph and, especially in the lowest range, also the boldest one. This means that the low range of the frequency spectrum is particularly loud. In fact it shows a very strong octave and the following overtones are remarkably present until the nineteenth.



Cypress has perhaps the most distinctive spectrum: it has a strong octave, while subsequent overtones decrease rapidly in presence until the obvious leak at around 2000Hz. After this point two other strong areas around 3000-3300Hz and 6000-6200Hz are visible on the graph.



Maple shows by far the thinnest graph, especially in the lowest range and it has a rather weak octave. While not presenting obvious leaks, excepting perhaps the fifteenth, it is remarkable that after 5500 Hz the decrease in volume is very gradual.



In addition to the graphs, to give a more close idea of what the actual difference in sound really feels, I made some mp3 samples where the same short passages, taken from Sweelinck's *Pavana Lachrimae*, can be heard on different soundboards in a row. I chose to record the first part of this melancholic piece for several reasons:¹³⁰ it sounds very well on the clavichord, it fits the small compass of this instrument, it both contains homophonic and melismatic passages and the slow tempo emphasize the timbre of the instrument.

The file **Passage1FSCM.mp3** contains bars 9-15 of the *Pavana*, which I chose to give an example of chords connected by eighth notes. **Passage2FSCM.mp3** contains bars 23-24 and gives instead an example of sixteenth motion. They both stay roughly within the central range of the instrument (c to c"). The order in the recording is always: Fir, Spruce, Cypress and Maple, as the filename suggests. Each sample is separated by 2 second of silence. I preferred to cut chunks from a full performance than to play just the passages chosen, as this would be even farther from live experience. While it is possible to hear some differences also in these audio samples, I would once again stress the fact that, while playing, the variance in timbre was still not big, but obvious to hear. I would also remind that while we normally compare the sound of very different instrument, here we are comparing the very same clavichord with similar soundboard made of different material.



Sample soundboards before recording. (From the right: Maple, Cypress, Spruce, Fir, Larch¹³¹)

¹³⁰ Jan Pieterszoon Sweelinck, *Pavana Lachrimae*, bars 1-32.

¹³¹ Since I had some spare pieces of Larch in my workshop I couldn't resist the temptation of trying to make a soundboard out of them. It was just a matter of curiosity: Larch was, as far as I know, never used in historical soundboards. There are indeed some good reasons for avoiding it: while being tough and resistant, this wood is also rather heavy and full of rosin. In my experience it also moves too much to be generally useful in instrument making. For all of these reasons I won't report here measurements and tests made on Larch.

**APPENDIX FOUR:
(weights and dimensions of samples)**

Material	Piece	Weight	Length		Mean:	Width:			Mean:	Thickness:			Mean:	Spec.Weight:	Mean:
		g	mm			mm				mm			kg/mc		
Cypress	1	84,2	435,5	435,5	435,5	95,8	95,6	95,7	95,70	3,6	3,8	3,8	3,73	541,1	548,1
	2	86,5	436	435	435,5	95,8	95,7	95,7	95,73	3,8	3,8	3,8	3,80	546,0	
	3	76	436	433	434,5	84,5	84,4	84,5	84,47	3,7	3,8	3,7	3,73	554,7	
	4	74,4	436	432	434,0	84,2	84,1	84,2	84,17	3,7	3,7	3,7	3,70	550,5	
Maple	1	79,8	381	382	381,5	95,7	95,6	95,7	95,67	3,4	3,4	3,4	3,40	643,1	625,4
	2	76,1	370	373,5	371,8	95,7	95,4	95,7	95,60	3,4	3,5	3,5	3,47	617,7	
	3	76,2	373	374	373,5	95,7	95,5	95,7	95,63	3,4	3,5	3,5	3,47	615,4	
Spruce	1	53,2	412,5	412,5	412,5	95,7	95,5	95,7	95,63	3,5	3,7	3,7	3,63	371,2	378,3
	2	53,7	412,5	413	412,8	95,6	95,5	95,6	95,57	3,4	3,7	3,6	3,57	381,7	
	3	53,3	412,5	413	412,8	95,6	95,5	95,8	95,63	3,4	3,6	3,6	3,53	382,2	
Fir	1	68	413	413	413,0	95,8	95,7	95,9	95,80	3,4	3,4	3,4	3,40	505,5	509,0
	2	66,8	413	413	413,0	96	95,6	95,9	95,83	3,2	3,4	3,3	3,30	511,4	
	3	67,8	413	412,5	412,8	95,8	95,5	95,7	95,67	3,4	3,4	3,3	3,37	510,0	

**APPENDIX FIVE:
(stiffness measurement)**



Sample clamped in the fixture with the laser displacement recording its rest position before starting tests.

As I mentioned, we wanted to have a mean to compare of the different materials' stiffness. We used a laser to measure the displacement that happened between the unloaded and loaded status. The laser only provides voltage indications that are to be read through a tester: every small variation in the position of the board facing the laser is reported in for of a small voltage change. We did measure with an electronic caliper the actual positions of the board before and after we did the tests, to have an equivalent in mm of the voltage variation. It turned out that a variation of 1 Volt corresponded to a movement of 4,65 mm. We first planned repeating the test twice per sample, but as we got consistently the very same results, we agreed to repeat it only once. Unfortunately we had only two Cypress boards of the same width, so we could perform stiffness and damping test only twice for this kind of wood.

This test gives a simple comparison between materials stiffness, however this measurement in displacement, despite being in inverted proportion to the material stiffness, does not comply with standard stiffness indications. It is probably possible to derive such a value somehow, through mathematical formulas, knowing the board section, that the laser was laying exactly 280mm from the clamping point and that the weight of exactly 400g with a 40mm diameter was laid in the center of the board with its edge also at 280mm from the clamping point. My knowledge of statics are sadly far too poor this challenge.

Sample:	Rest	Loaded	Diff.	Displacement	Mean:
	Volts	Volts	Volts	mm	mm
Spruce 1	-0,057	-2,43	2,37	11,0	11,0
2	-0,248	-2,58	2,33	10,8	
3	-0,182	-2,58	2,40	11,2	
Fir 1	-0,347	-2,23	1,88	8,8	8,5
2	-0,115	-1,89	1,78	8,3	
3	-0,195	-2	1,81	8,4	
Cypress 1	-0,195	-1,799	1,60	7,5	7,2
2	-0,32	-1,826	1,51	7,0	
Maple 1	-0,592	-3,03	2,44	11,3	11,0
2	0,346	-1,96	2,31	10,7	
3	0,105	-2,27	2,38	11,0	
Calibration:	1 Volt =	4,65	mm		

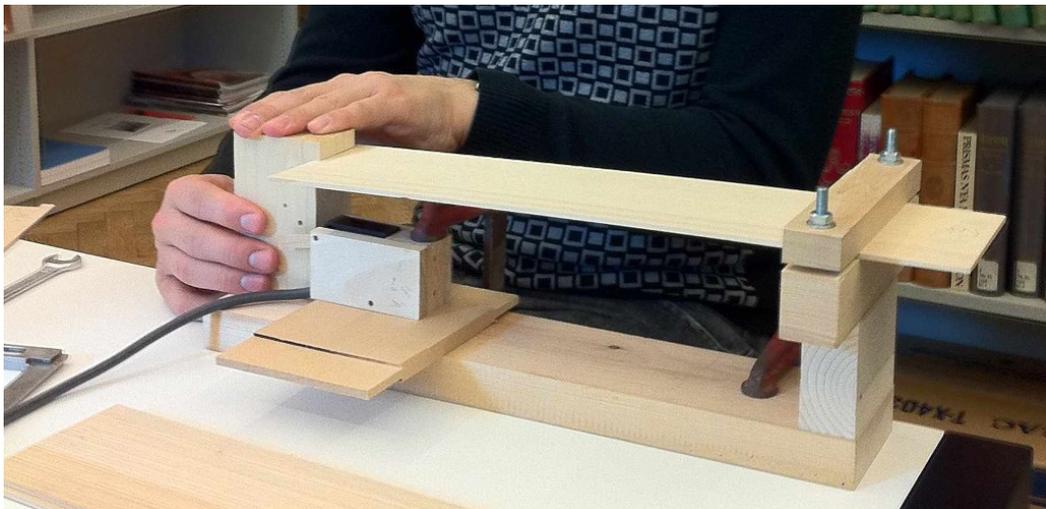


Loading the weight in its intended position.



Measuring the sample's bending at the given position.

**APPENDIX SIX:
(Vibration damping tests)**



Clamping the free end of the board before performing the vibrations' decay test.

As for the damping of the material, we used the same equipment and excited the samples in the way described above, while the computer plotted the waveform on screen for a time of 10 seconds: no vibration approached this limit. We repeated the test 3 times for each sample, as there were slight variations between the tries, and then made a mean. Since the very beginning of the oscillatory movement was sometimes irregular, we chose to start considering values from the 4th peak. We analyzed 10 cycles: from the 4th to the 14th.

Sample:	Ampl 1	Ampl 2	Periods	Log decr	Damping ratio	Mean sample:	Mean Material:
Spruce 1a	1,042	0,551	10	0,06371624	0,010140	0,00967	0,00918
1b	1,037	0,562	10	0,06125854	0,009749		
1c	0,832	0,469	10	0,05732297	0,009123		
2a	0,983	0,564	10	0,05555549	0,008842	0,00867	
2b	0,99	0,571	10	0,05503157	0,008758		
2c	0,902	0,532	10	0,0527971	0,008403		
3a	0,959	0,541	10	0,05724718	0,009111	0,00921	
3b	1,031	0,574	10	0,05856551	0,009321		
3c	1,053	0,591	10	0,05775825	0,009192		
Fir 1a	0,945	0,585	10	0,04795731	0,007632	0,00757	0,00746
1b	0,937	0,581	10	0,04779325	0,007606		
1c	0,944	0,59	10	0,04700036	0,007480		
2a	1,036	0,609	10	0,05313042	0,008456	0,00721	
2b	0,663	0,439	10	0,04122756	0,006561		
2c	0,66	0,436	10	0,04145976	0,006598		
3a	0,846	0,545	10	0,04397336	0,006998	0,00761	
3b	1,061	0,643	10	0,05008224	0,007971		
3c	1,065	0,65	10	0,04937577	0,007858		
Cypress 1a	1,125	0,672	10	0,051528	0,008201	0,00813	0,00802
1b	1,139	0,683	10	0,05114111	0,008139		
1c	1,119	0,675	10	0,0505478	0,008045		
2a	1,037	0,628	10	0,0501547	0,007982	0,00792	
2b	1,004	0,612	10	0,0495015	0,007878		
2c	1,041	0,634	10	0,04958881	0,007892		
Maple 1a	0,791	0,522	10	0,04156304	0,006615	0,00661	0,00774
1b	0,799	0,529	10	0,04123725	0,006563		
1c	0,829	0,546	10	0,04176012	0,006646		
2a	1,487	0,865	10	0,05417864	0,008622	0,00844	
2b	1,511	0,891	10	0,05281825	0,008406		
2c	1,496	0,888	10	0,05215784	0,008301		
3a	1,325	0,796	10	0,05095686	0,008110	0,00817	
3b	1,319	0,783	10	0,05214965	0,008300		
3c	1,317	0,792	10	0,05085503	0,008094		

6. Conclusions

On the experiments

While carrying out tests on the samples was an interesting experience, I found it difficult to find correlations between the results of measurements and the actual behavior of soundboards. In particular, I was expecting to find parallels between the material damping and the sound decay pattern of the instrument. However, since the clavichord is a touch-sensitive instrument and sustain highly depends on the energy transferred to the strings while hitting them, I had no way to make sure that a certain decay pattern depended on the soundboard and not on playing more or less loudly. Trusting my subjective impression, I would say that the material has not a major effect on sustain. Some notes simply sounded longer or shorter on whatever wood, indicating that the reason for this was to be found somewhere else; some other notes changed from material to material, without a clear pattern. On the basis of my building experience I would say that thickness of the board and barring pattern affect sustain clearly more than the material itself. On the clavichord, in particular, also the interaction between keylever, rack, tangent and strings also plays an important role: if strings are hit exactly simultaneously or if the keylever blocks against the rack, the sound development is blocked too.

Loudness is also controlled by the player's touch and there is no way to tell in a recording if the instrument sounded softer or louder, because of the material or because of the player. On the other hand, while playing, since you have full control, it is possible to judge the soundboard's loudness reliably. I didn't recognize any correlation between loudness and damping or loudness and stiffness, but I identified a rather obvious link with the material weight. The lighter materials had an obviously louder sound, while those with the highest specific weight had the softest. This was not really surprising: it is widely known that any weight applied to the compound of bridge and soundboard can damp the sound, as we can see in violin mutes (*sordino*).

On historical evidences

Here we go back to the initial question: which was the *Klangvorstellung* of the old masters? In other words: how did builders from a certain area come to a certain preference? And how do the results of my work relate to historical evidences from instrument and sources?

First of all it must be noticed that for most regions there is little trace of experimentations with different materials and when this was the case, it seems that the earlier time periods were less standardized than the eighteenth century. In fact in some cases, like Flanders, soundboard standards were set once and for all in the sixteenth century. On one hand this means that the instruments probably were very well suited to the customers' expectations. On the other hand this leads me also to think that the "experimental" phase took place early and once a good solution was found, it became a universal standard through internal guild regulations. Italy is a clear exception to this general trend: while several features of the instruments remained surprisingly constant over centuries, the use of different materials in soundboards is documented for the whole period even within the same building center.

Starting with the wood most commonly found in sources and instruments, **Spruce** and **Fir**, one has to admit that they have a somewhat similar character, yet not the same. The impression that Fir had a slightly more bright sound, while Spruce a somewhat rounder and more fundamental one, was shared by all those who had a chance to play the instrument. Moreover, Fir has a particularly nice treble range, while Spruce has the most convincing basses among all samples. Given the similarity, however, I suspect that preferences may partly be related to their natural distribution. It is

hard to draw any conclusion on the specific use of each of them, since, as I said, several wood identifications may not be reliable. For this reason it would be very helpful if catalog curators in the future could start to pay more attention to this relevant detail.

Considered as a whole, we can infer that the old masters used Fir and Spruce because they deliver a powerful sound. We must consider that before the rise of the modern piano, excessive loudness was never a problem on stringed keyboards, but a weak sound was a serious risk. Indeed to build a loud instrument, as Adlung reports, was a difficult goal to achieve for instrument makers.¹³² Especially on clavichords, since the energy produced is so little, it is vital to make the most of it. Since a lighter board is set in motion more easily than a heavier one, it is a clear advantage of Spruce and Fir to be among the lightest woods found in Europe. So I tend to link the use of these woods to the preference for a loud, bold and round sound.

Cypress and **Maple** on the other hand, are not at all among the lightest woods and also show a more characteristic sound. It is difficult to prove that Italian makers chose this wood for its timbre, but also the contrary is true: since the use of Spruce and Fir was known in Italy from the very earliest times, it would be odd that builders didn't use these latter more often, if they had preferred the sound. There are many other reasons that speak certainly for using Cypress, like its elegance, durability, stability,¹³³ insect resistance and the nice smell. But there are also reasons that speaks against: even in historic times it was not as common as other woods (especially if one is looking for long, knot-free planks) and for sure it was not so easier to work with. Similarly Maple has a great appearance, but it's a hard work to plane by hand a thin board of this material. If the Maple tradition was limited to the city of Naples and was eventually discontinued after the sixteenth century, the Cypress tradition was widespread and lasted for three centuries. I tend to think that the peculiar sound of this wood must have played a role in keeping it alive.

While I never heard another Maple soundboard for comparison, I was surprised as I recognized the cypress soundboard in my clavichord had some Cypress "character": my instrument still sounded clearly like my instrument, but with this soundboard it assumed part of the color that I heard in other instrument made with this wood. Therefore, I have even more reasons to think that this peculiar character did not escape the attention of the old masters and that it was indeed an intentional acoustical choice to build instrument out of Cypress.

On the playing experience

It is very difficult to draw conclusions on whether some repertoire works better with a certain sound, even not considering the fact, already discussed in the introduction, that it is very difficult to link a certain composition to a particular instrument. We must take our habits into account: since we are used to listening to Italian music played on Cypress instruments, we may easily get the impression that Italian music requires that sound in a sort of circular mechanism.¹³⁴ Indeed I found that all sounds suited well Sweelinck's music well, as they all allowed a musical performance and each underlined with its own character some aspects of the piece. Personally, for this piece I slightly preferred Spruce, as it reminds me of a lute sound. Spruce was used in the Low Countries in Sweelinck time: is that the key? I don't think so: if I had played the brilliant *Ballo del Granduca* instead of the melancholic *Pavana Lachrimae*, my preferences would probably have been different. As an organist I am used to linking the sound to the character of the piece. This is instinctively more relevant than other aspects, like the provenance of the music.

132 See pg. 21.

133 Dimensional stability may indeed have played a more important role that we may now think. Especially for those Venetian instruments, that were build on the humid *Laguna* and then exported everywhere.

134 I'm sure if one would have asked to nineteenth century listener which is the best instrument for Bach's keyboard works, most of them would have answered that it is the piano. I have no reason to doubt that we are similarly conditioned by the musical standards of our era.

It was interesting to discover that other musicians who tried, or listened to the instrument got the same impression that I did. They also agreed on the fact that in the recording, much of this difference disappears. Some reported that different soundboards felt different in touch. This is to be expected, as on the clavichord we tend instinctively to press the keys harder to compensate for a softer or thinner sound. So, as could be expected, the Maple soundboard was reported to be “harder”.

After all tests and recordings have been carried out, I decided to plane the soundboards according to typical historical thicknesses. I waited until after recording on purpose, because it is much more difficult to obtain boards of similar dimensions following an irregular pattern than just making them flat: big inequalities could have invalidated the whole work, I feared. So I did at first avoid anything too advanced, but I still was curious to see what would happen. I discovered my fear had no foundation at all: on one hand thickening the boards really changed the sound, improving it.¹³⁵ On the other hand the character of the wood that I had noticed before, became even more obvious. Finally I decided to glue also a cut-off bar in the left corner, on the underside of each soundboard. These bars are made of Spruce, have all a similar shape and run parallel to the bridge at a distance of 72 mm. Again, the sound was improved, becoming more solid, but the character is unchanged. Therefore, it appears that the influence of the material on the sound, even if it is smaller than that of some other parameters, is indeed important, as it seems to be independent from other aspects.

On the basis of this experience, in the future I will use Spruce as general purpose wood especially on clavichords, where a loud and warm sound is required. I will use Cypress where a more crisp and reedy character is desirable, or where the expected environmental conditions makes it vital to have a particularly stable soundboard. I will give future customers the opportunity of trying this instrument to be able to feel the differences and I will also give them the possibility of choosing Fir or Maple as soundboard material if they wish.

¹³⁵ My impression was that volume and sustain improved, especially in the treble. Of all materials, Maple was the one which had the biggest benefits.

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