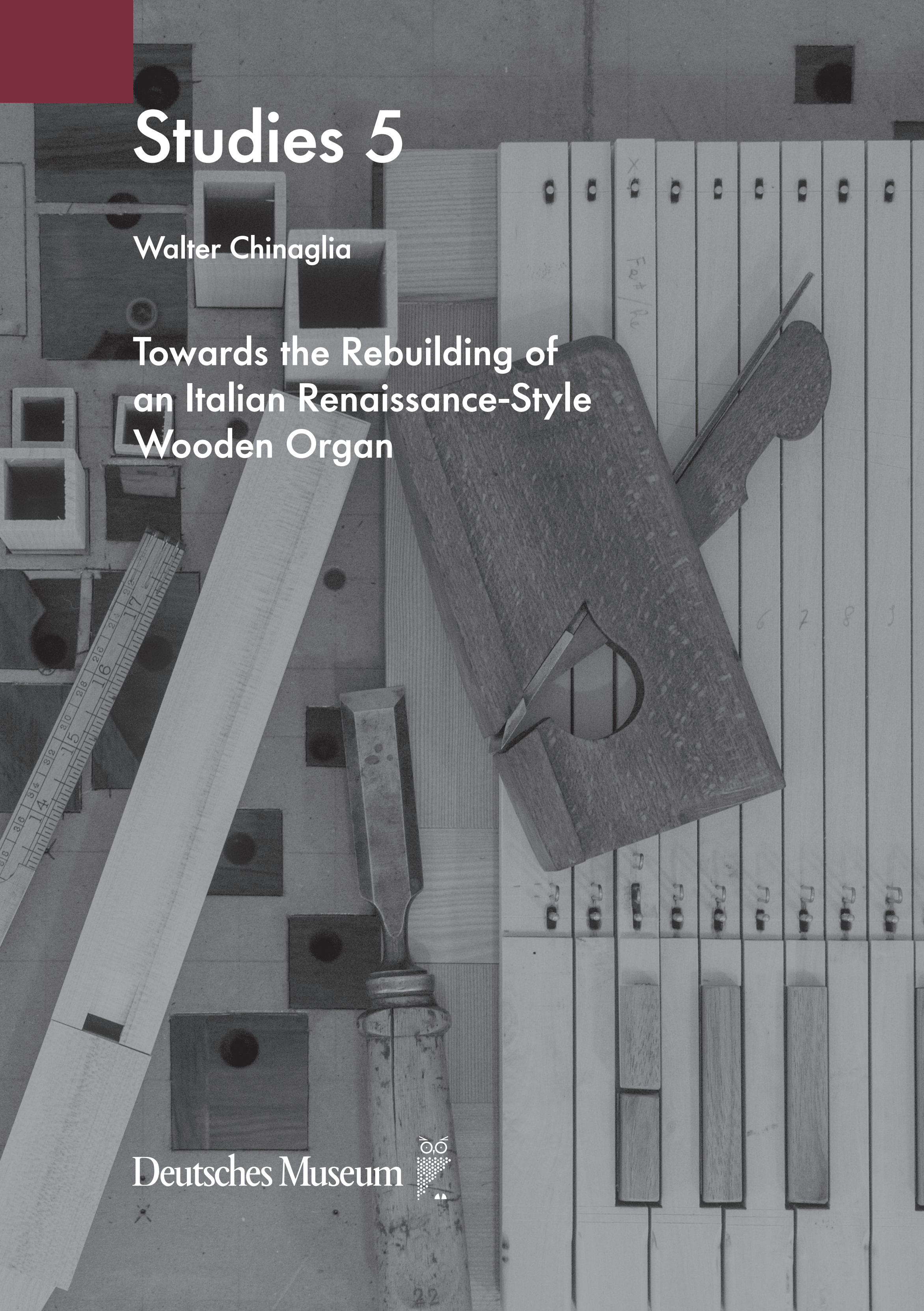

Studies 5

Walter Chinaglia

Towards the Rebuilding of an Italian Renaissance-Style Wooden Organ

Deutsches Museum

Towards the Rebuilding of an Italian Renaissance-Style Wooden Organ

Deutsches Museum Studies

Edited by Eva Bunge, Frank Dittmann, Ulf Hashagen, Marisa Pamplona-Bartsch, Matthias Röschner, Helmuth Trischler

Volume 5

After obtaining his degree in Physics in 1996 and completing five years of research in nonlinear optics at the University of Insubria, Como, *Walter Chinaglia* opened his workshop Organa in 2001. He is internationally renowned for building historically informed pipe organs and harpsichords, using traditional materials and historical techniques. He is official luthier of the International Course on Medieval Music Performance in Besalú, Spain, and affiliated to the Centre for Cultural Heritage Studies, University of Insubria, Como. In 2018 he was research fellow at the Deutsches Museum within the research group Materiality of Musical Instruments, funded by Leibniz Competition.

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Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der
Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind
im Internet unter https://dnb.de abrufbar.

Walter Chinaglia, "Towards the Rebuilding of an Italian Renaissance-Style
Wooden Organ"
1st Edition

Editing: Paul Kilbey, Andrea Lucas
Layout and Design: Jutta Esser
Cover illustration by Marco Lamperti
Printing and binding: Steininger Druck, Eichenried
ISSN 2365-9149
ISBN 978-3-940396-97-6

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Preface

Musical Instruments as Material Culture

by Rebecca Wolf

Walter Chinaglia's study in Renaissance organ reconstruction is an important example of the work of our research group "Materiality of Musical Instruments: New Approaches to a Cultural History of Organology". The study combines theoretical and practical work in an instructive manner.

Chinaglia underpins his hands-on building of a pipe organ based on the historical *organo di legno* housed in the Silberne Kapelle in Innsbruck, Austria, with extensive knowledge of historical craft, acoustics, and musical practice. Besides referring to the aforementioned "original" organ, Chinaglia consults early theoretical writings, images, and manuals in order to reconstruct authentically not only the historical instrument's appearance and feel, but also – and perhaps most importantly – its sound. Furthermore, he employs historical techniques for organ building such as installing hinges, preparing wooden plates, using colour and using bone glue, thus simultaneously reviving historical craftsmanship. Nonetheless, present-day knowledge of acoustics and craft also informs his research and rebuilding methods.

Like most musical instruments, the organ is a material object that is produced to create music, which is ephemeral by nature, and often described as immaterial. From the standpoint of acoustics, sound and music are *not* immaterial, although sound waves cannot be seen or touched. Musical instruments help bring the material aspect of music to the fore and thus serve as a concrete medium between music-making and the music itself. Especially regarding music that existed in the distant past, historical musical instruments bear testimony to how such music sounded. They serve as bridges to an acoustical past.

I view Chinaglia's study as an invaluable contribution to current research in organology as well as in material culture studies, as it tackles fundamental questions associated with rebuilding historical musical instruments: what is the focus of the process of reconstruction – the physical object, the artisanship, or the sound? Which aspect is given priority when circumstances do not allow all aspects of reconstruction to be authentically fulfilled? To what extent are an instrument's appearance, haptic feel, and sound dependent on how it was crafted? Thus, I would like to sincerely thank Walther Chinaglia not only for his openness in communicating and collaborating with our research group but also for charting a path in the uncertain terrain of combining theory and practice, utilising his knowledge of acoustics and craft as well as writings in music theory. To further elucidate the importance of Chinaglia's work for our research group, the following section offers a brief insight into the theoretical discussions surrounding such terms as materiality, technology, and craft knowledge, which inform our understanding of a cultural history of organology.

Tools and techniques

In ancient times, philosophers such as Plato and Aristotle discussed the relationship between tools and their human users in the context of the term "organon". More recently, historians of science have built a more sophisticated framework for discussing this topic.

Francesca Bray and Pamela Smith[1] both bring the terms tools and techniques into a close relationship with matter, experimenting, and craft. Bray defines techniques as "the skilled practices that go into the material production of knowledge as well as the production of artefacts", and contrasts it respectively with science – the knowledge about natural processes – and *technology* – systems and networks related to the other two terms.[2] For music and sound, this concept of "skilled practices" can open up ideas about the relationship between material artefacts like instruments, and techniques of music-making. The knowledge of processes is essential in both making artefacts and making music. The processes involved include the transformation of a material into an artwork or artefact, and music-making skills, which are integrated into networks that Bray calls *technology.* Regarding the material as the starting point, Pamela Smith writes, "all science begins in matter".[3] Conceptually, she utilises "the interface of the human senses and human body" to develop her idea of *techniques* by focusing on sensual perception. How can we transform this concept for musicology and organology? Connecting the experiences with raw material, instrument-making and playing instruments also enables us to advance in the field of musicology. These concepts of *techniques can* connect physical objects and ephemeral music.

Walter Chinaglia's project is a study of experimenting with material, craft, early technology, and moreover with modern tools of acoustic measurements as spectral analysis. Different sorts of pipes, stopped or Principale, sound with differently composed series of harmonics. The use of Principale wooden pipes is of special interest for this project, as their use is today unusual for the performance practice of early music. It is more common to use stopped wooden pipes or Principale pipes made of metal. The music of the rebuilt instrument using Principale wooden pipes might effect a different hearing, different from our habitual hearing categories. Furthermore, the toolkit of spectral analysis makes the difference visible.

1 Francesca Bray, "Science, technique, technology: passages between matter and knowledge in imperial Chinese agriculture", *The British Journal for the History of Science* 41 (2008), no. 3: 319–344. Pamela Smith, "The history of science as a cultural history of the material world", *Cultural Histories of the Material World,* ed. by Peter N. Miller, Ann Arbor: University of Michigan Press, 2013, 210–225.

2 Bray, "Science", 320.

3 Smith, "History", 215, 216.

Materia and materiality

It seems worthwhile to think about the notion of *materiality* more generally, and to consider what the term typically denotes in music scholarship today. For instance, it is used to describe compositional structures in musical works, physical aspects of music, such as spatial factors influencing acoustics, as well as the influence of material objects on music and sound. Furthermore, materiality plays an important role in the research of manuscripts and printed books. Let us turn our attention to the basis of the term materiality: the material. The term *material* can mean the subject of a composition as well as parts of a musical piece, such as melody, harmony, rhythm, or dynamics. Both usages refer to the composition and its performance, as a piece of art, a more or less complex creation that allows for structural analysis and interpretation. What can we learn about music, when we consider the material aspects of the physical instruments – in Chinaglia's case, the wood, which constitutes the organ?

Here, theories of the relationship between material and form during the nineteenth century and earlier are relevant. The Latin *materia* is related to substance and the basis of a thing. This *materia* can be modified and formed, and out of this *materia* something can be built.[4] Both form and function of an object become important in the process of creation. In a musical piece, temporality too comes into focus. The material is the starting point for the further development of form. In a musical instrument, form, function, and material are joined in a very particular manner, because the instrument is a tool that produces signs and sounding semantics. From this perspective, the aesthetic and sensory experience of playing and listening to musical instruments becomes central.

The instruments can be perceived sensuously in many ways, for example by testing the vibration and acoustic behaviour of material, as Chinaglia also describes.

In order to help contextualise the relationship of material and form, let us go back to Immanuel Kant's *Critique of Pure Reason* (1781), where he contrasts the material – the object of perception – with the form of an artwork, in which the well-organised proportions are of interest. Form is necessary for analysis, as Kant notes: "I call that in the appearance which corresponds to sensation its matter, but that which allows the manifold of appearance to be ordered in certain relations I call the form of appearance."[5]

Material and form are complementary in the process of creating an artwork. The material can only be of a certain form or shape; aesthetic judgements – which are mostly based on the interpretation of the form (proportion, harmony, relationships) – cannot be traced back to the material itself. Transferring this theory to musical instrument-making, material and form seem to coalesce. The result of the instrument makers' work, and often

4 The luthier Martin Schleske identifies particular trees which carry the potential to bear "Klangholz" – the starting material in making violins. Martin Schleske, *Der Klang: Vom unerhörten Sinn des Lebens,* 3rd ed., Munich: Kösel, 2011, 14.

5 Immanuel Kant, *Critique of Pure Reason,* trans. P. Guyer and A.W. Wood, Cambridge: Cambridge University Press, 1998, 172–173.

experiments for improving sounding results, is a physical object, which is invented and created with the aim of producing sound and music – an ephemeral art.

An even more controversial contribution to the topic of substance and form than Kant's was Georg Wilhelm Friedrich Hegel's *Aesthetics: Lectures on Fine Art* (1835–1838), which juxtaposed the concept of material with that of the idea. Hegel is concerned with the mental production of the artwork itself. The process of this production involves transforming and reshaping the material in order to give shape to an idea or form to the ideal. Hence, the material and the ideal are placed in a strict hierarchy, where the form and the ideal occupy the highest position.[6] In this way, Hegel declares the overcoming of materiality. This, however, does not mean that he was not generally interested in the characteristics of substances. In "Material der Skulptur" (1835/42), he systematically describes the characteristics of wood, ivory, marble, gold, and other metals for creating sculptures. The particular characteristics of each material significantly influence the form and function of the resulting artefacts produced by the sculptors. For Hegel, too, the creative process influences the artwork, but the result does not highlight the material, because only the form is important at the end of a process. The idea of the creator is manifested in the form.[7]

In musical instrument-making, this idea relates on the one hand to music as an ephemeral artwork, and on the other to the musical instrument as an artwork in itself. In both cases, the role of the material is the foundation of a process.

Re-constructing, re-building, and re-sounding

Musical instruments carry enormous – if as yet untapped – potential to spark debates in the fields of historical musical culture and performance practice. They are also invaluable resources for researchers. Fascinating insights on human interaction with material objects can be gained while composing, making music, and listening.

Instruments influence our performance, reception of music, and music theory. Their material substance and history transport knowledge of building, conceptualising and usage. Organology, in general, bridges the gap between aesthetics and research on objects.

A project like Chinaglia's rebuilding of a Renaissance wooden organ highlights the importance of carefully considering a wide scope of issues: from constructional concepts to using special substances such as different sorts of wood, colour, metal, and glue under present conditions. Re-shaping the organ's individual parts and combining them into a

6 Georg Wilhelm Friedrich Hegel, *Aesthetics. Lectures on Fine Art,* trans. T.M. Knox, Oxford: Clarendon Press, 1975, vol. I, 164: "The artistic presentation must appear here as natural, yet it is not the natural there as such but that making, precisely the extinction of the sensuous material and external conditions, which is the poetic and the ideal in a formal sense."

7 Georg Wilhelm Friedrich Hegel, "Material der Skulptur", *Werke in zwanzig Bänden,* vol. 14: *Vorlesungen über die Ästhetik II,* Frankfurt am Main: Suhrkamp, 1970, 437–444.

functional sounding musical instrument requires fundamental knowledge in operating mechanics and craft skills. The decision to rebuild the physical object itself as the project's main aim opens up the question of the influence of copying all constructional steps on the sounding result. Will the exact copy of the material object automatically result in a copy of the historical sound? What do we know about this sound and how does this knowledge influence the production process of re-building? Walter Chinaglia's project is one important step towards tackling these complex research questions. It is part of a vivid field of cultural heritage, of theoretical and practical research on objects, in this case on musical instruments as well as on music itself.

Introduction

This volume reports on an ongoing project to build a pipe organ modelled on the sole extant Renaissance *organo di legno* (organ with wooden pipes), which is in the Silberne Kapelle of the Hofkirche in Innsbruck, Austria,[8] and shown below.[9] The new organ (at the moment still under construction) will be an *organo positivo di legno*, resembling one of the largest among the *organi di legno* as described by early sources.

During my residency at the Deutsches Museum,[10] I built the main parts of this new organ, in four sessions. During the first session, I constructed two ranks of pipes in cypress wood, a Principale and a Flauto. The second session concentrated on the construction of the windchest. The third session was focussed on the building of bellows with five ribs. In the fourth session, I worked on the keyboard and mechanical action.

Nevertheless, this volume contains a wider overview of the organ rebuilding, including schedules on woodworking, tools, special jigs, and alternative solutions for the windchest and rollerboard.

Chapter 7 is devoted to the investigation of the sound spectrum of some newly built pipes. This demonstrates that wooden pipes dimensioned on historical parameters (size, mouth cut-up, mouth width, etc. from the Silberne Kapelle organ) produce "authentic" sound: it is coherent with descriptions from early sources and consistent with the sound produced by historical metal pipes.

The organ-case is under construction in my workshop in Italy at the moment, and the organ as a whole will be finished by summer 2020.

The origin of this project

This new project is based on my recent research project, *Duoi organi per Monteverdi*,[11] which resulted in the construction of two smaller Renaissance-style organs with open wooden pipes.

8 The main paper about the last restoration of the Silberne Kapelle organ is Pier P. Donati, "L'organo della Silberne Kapelle di Innsbruck", *Informazione Organistica* 13 (2006): 57–94. Other sources are listed in the bibliography.

9 In the period between 1950 and 1952 this instrument was completely restored by Hubert Neumann under the direction of Egon Krauss. See for example: Egon Krauss, "L'organo della 'Silberne Kapelle' di Innsbruck", *L'Organo. Rivista di cultura organaria e organistica* V, no. 1 (1964–67): 20–30.

10 I had a two-month fellowship in summer 2018 as Organ Builder in Residence in the Materiality of Musical Instruments research group headed by Dr. Rebecca Wolf. Particular thanks go to her, as well as to Dr. Leon Chisholm, for all their support. I am grateful to family, friends, and colleagues in Munich who have read drafts of this publication.

11 See https://www.organa.it/monteverdi/, accessed 31 August 2019, and Walter Chinaglia, "Deux orgues pour Monteverdi", *La Tribune de l'Orgue* 78, no. 4 (2018): 35–39.

The enthusiastic feedback I received from expert musicians and musicologists encouraged me to investigate in greater depth the organ of the Silberne Kapelle in Innsbruck, which is the sole, invaluable resource for studying the style, sound and dimensions of wooden pipes.

As was conventional, early Italian organs were based on the two families of open flue pipes, namely Principali (narrow-size pipes) and Flauti (large-size pipes). Most of the pipes of the Silberne Kapelle organ are made of wood; only a few ranks of high treble pipes are metal. A reed stop was originally located on the rear part of the windchest, but it was substituted in the early years by the beating stop called Fiffaro.

As well explained by the attentive last restorer Pier Paolo Donati in his report,[12] the organ was manipulated a lot during his life: it was dismounted to be moved from Italy to Austria, then repeatedly restored, unfortunately not always with conservative finality.

Consequently, pipes were mixed up, cut or lengthened, and re-voiced to be adapted to their new location (the early order has been established after the last philological restoration).

The original bellows, typically situated in the lower part of the case, are lost; in their place, a separate set of bellows was built and placed behind the organ as an independent structure. The pedalboard was added later. Despite all these vicissitudes, the Silberne Kapelle organ remains the most authoritative and exhaustive reference from which to rebuild historically informed *organi di legno*.

Up to now, many organ builders have taken inspiration from this organ when developing their own organs, but none of them – to the best of my knowledge – has ever made a copy or a close version of it. The reason for this is probably the need to satisfy the early music instrument market, which asks for handy, practical instruments.

I have been exploring and studying the organ as a united, uniform organism in which early-modern art, music, science and craftsmanship converge. In my work as a builder of organs in historical styles, my philosophy is to apply only historical building techniques and to use tools and materials that were available to builders from the historical period in question.

I am persuaded that this approach strongly influences the design and operation of the resultant artefact, as well as the builder's conception of the organ.

Therefore, pursuing the path undertaken with *Duoi organi per Monteverdi,* I am searching for the most authentic and integral approach to rebuilding a historically informed *organo di legno* based on the Silberne Kapelle organ.

12 See Donati, *L'organo,* 2006.

1. On the advantages of making a new early organ based on the historical model

Introduction

Reading the “New O.H.S. Guidelines for Restoration”, we can clearly see that one of the advantages in building a new organ modelled on a historical one is an opportunity to overcome the limitations encountered in the original instrument.

Starting from article 3, point B/5 reads:

> Although historical design, materials, or workmanship may sometimes fail the current restorer’s standards of quality, they nevertheless give authoritative testimony of the past maker’s knowledge, skill, or judgment and deserve respect as historical evidence. Every effort should be made to retain such work whenever possible.[13]

In the case of the organ of the Silberne Kapelle, a reconstruction offers the following opportunities:

- reshaping the case and restoring its original dimensions, in order to make room again for the two bellows (at the moment, a set of bellows – not original – is placed behind the organ as independent machinery);
- reproducing the original sound (today’s sound is modified due to ageing and several restorations);
- recreating the *ripieno* by using exclusively wooden pipes;
- adding split keys (split keys offer many possibilities in order to accommodate a wider Renaissance repertoire);
- reintroducing the original reed stop, which was substituted during early years by a new, more popular stop, Fiffaro.

Generally, I am convinced that only by following the entire process – from wood to sound, so to speak – can we obtain a deep comprehension of what this organ (like its no longer extant contemporaries) is truly about.

Having the original organ as a model, I have the unique privilege to rebuild it as if I were under the guidance of the old master who originally created it, by reading and following his views, his decisions, and by applying the workmanship, methods and tools of his time.

Thus my early-modern organ will be strictly related to the original not only for the sound, but also with regard to the whole construction process, including the project and building techniques.

13 Issued by the U.S.-based Organ Historical Society (O.H.S.): Scot Huntington, “The New O.H.S. Guidelines for Restoration”, *ISO Journal* 57 (2017): 7–35, here specifically see 26–35.

My aim is to gain the deepest possible knowledge and comprehension of the workmanship of the era, and to be able to rebuild missing parts (or integrate early elements such as split keys, bellows, and the reed stop) without affecting the style.

1.1. Reshaping the organ-case

One of the main advantages of building a new organ modelled on the one at the Silberne Kapelle is the possibility to restore the original shape of the case.

Typically, Italian small positives/chamber organs were built in the form of a cupboard in two sections, the lower case containing the bellows, the upper case the rest of the organ. Quite often the lower section was deeper, to accommodate two bellows, positioned side by side.

The lower case of the Silberne Kapelle organ today shows the same depth as the top one, and it is partially occupied by the pedalboard (not original). According to the hypothesis of Pier Paolo Donati,[14] the lower case of the Silberne Kapelle organ was originally deeper, as suggested by the two original carved panels, today used as doors on the right sides of the organ,[15] shown in Fig. 1.1.

In a modern rebuilding of the organ of the Silberne Kapelle, one possibility would consist of removing the pedal (not original) and enlarging the lower case in order to hold two large bellows put side by side. But instead, I decided to arrange them differently, by maintaining the pedalboard as it is (which occupies a large portion of the lower case), stacking the two bellows, and placing them close to the rear panel. Their wedge shape suggests that they can be stacked like two halves of a rectangle in which the diagonal delimits the maximum opening angle. This disposition is space-saving and simplifies the lifting mechanism (not yet built).

1.2. The advantage of making a new early organ: sound

We can take advantage of the organ builder's huge expertise in historical metal flue pipes to say that when restorers analyse languids and lip edges under a strongly magnified view, they clearly see that each tool and every movement leaves behind specific traces. All these small actions influence the timbre in an inimitable way. This is also true for the effect of time, as aged pipes (in our case 400-year-old wooden pipes) certainly present altered surface structures at the level of the languid (block) as well as the lip edges (even when not modified by any organ builders).[16]

If we attentively build our organ by exclusively using the appropriate materials, early voicing tools and precise artisanal manipulations, the chances are high that we will achieve the historically accurate sound of an *organo di legno*.

14 Donati, *L'organo,* 2006.

15 See Fig. 2 in ibid.: 82.

16 Cf. Pentti Pelto, "A new aspect to voicing", *ISO Journal* 57 (2017): 61–71.

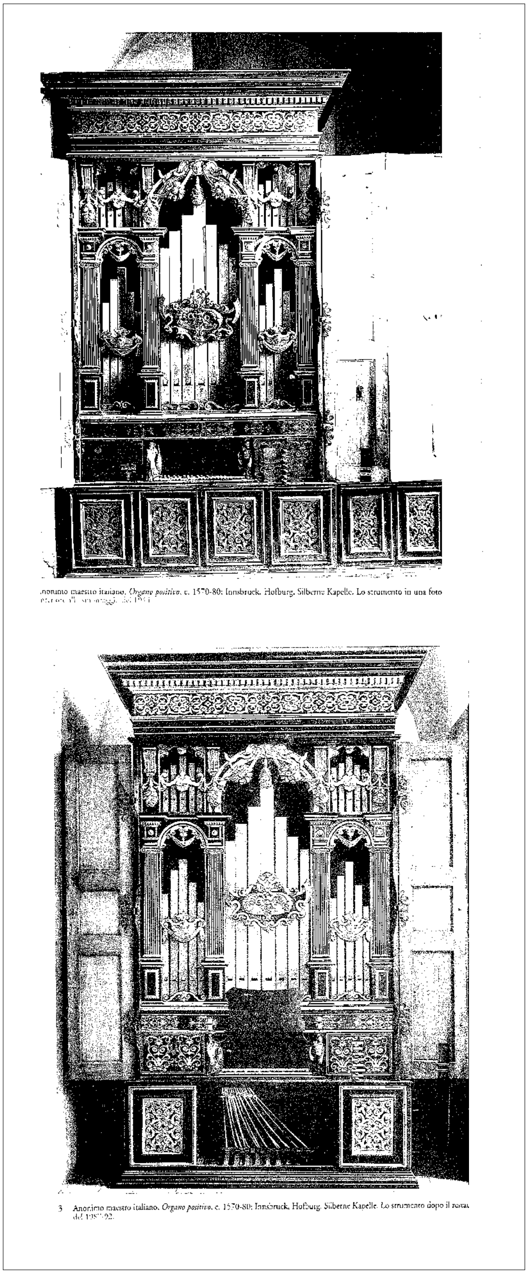

norumo maestro italiano, *Organo positivo*, c. 1570-80; Innsbruck, Hofburg, Silberne Kapelle. Lo strumento in una foto
3 Anonimo maestro italiano, *Organo positivo*, c. 1570-80; Innsbruck, Hofburg, Silberne Kapelle. Lo strumento dopo il restau

Figure 1.1

1.3. Reproducing a natural, unforced sound

I strongly believe that a perfect sound from a wooden pipe can only be achieved if it comes naturally from the newly built pipe, in one or two strokes: when mouth cut-up is wisely chosen and the wind-way is properly opened, no other adjustments being necessary (such as toe hole regulation, or tricky positioning of the mouth cover).

The key to obtaining a good steady-state sound combined with a proper sound attack comes through combining physics with manual skill; this reveals the full potential of the resonator. Skilled artisanal manipulations and sensitivity from the organ builder are needed to create this gentle speech characteristic that emerges from the pipe naturally, unforced. The wrong approach, however, is defining the desired sound beforehand and trying to obtain it by adapting the pipes' parameters afterwards: that is to say, by imposing a sound on the pipe.

The old master was undoubtedly so experienced that he could feel how his pipes would sound based on their main parameters, even before hearing them for the first time.

The voicing of wooden pipes merits more in-depth attention. Metal pipes offer many voicing possibilities thanks to the malleability of the material, while wooden pipes are much more rigid since the material limits the possibilities to a few edge corrections. In fact, the upper lip is in a fixed position (it cannot be adjusted inside or outside to match the air jet), the foot-block is also fixed (whereas a metal languid can be lifted up or lowered slightly) and the wind-way (flue width) can be set only once and cannot easily be reduced. Also, edge corrections are not reversible.

Although this vulnerability sometimes leads to failure (after one or two attempts a new pipe is required), it is also a unique chance to track down the historical sound: as all parameters (resonator geometry, mouth proportions, mouth cut-up, flue width, wind pressure) converge to define the pipe's speech, they lead us automatically and unquestionably to a precise final sound.

I voiced my open wooden pipes mainly by setting the flue width and slightly correcting the mouth edges (not the cut-up). The effect/incidence of these two parameters in the sound creation of wooden pipes is generally underestimated by organ builders (and not often enough explored); voicers therefore prefer to work with higher mouth cut-ups which correspond to a more stable condition. Unfortunately, the cut-up has a direct effect on the spectrum (much more than the material of the walls) and sound attack. However, I am convinced that the anonymous master so wisely shaped and sized his pipes to naturally produce the sound he had in mind, that only minimal adjustments were required.

By precisely following his measurements and parameters for the wooden pipes of my reproduction, we shall expect their sound to be almost identical to an imagined early-state sound of the Silberne Kapelle organ.

1.4. Split keys[17]

Musicians who regularly perform Renaissance music are well aware of the convenience of split keys in organs that are tuned in meantone temperament. Without split keys they would experience too many limitations, so I decided to add them as follows:

- first octave: Re/Fa#
- second and third octaves: Re#/Mi♭ and Sol#/La♭
- fourth octave: Re#/Mi♭

For a detailed explanation of the split keys, see Chapter 4.

17 Since this paper is about the Italian organ of the Silberne Kapelle, I will use the Italian names for keys (Do, Re, Mi, Fa, Sol, La, Si) instead of the international ones. The lower octave is labelled with the subscript 1, the second with 2, etc. Sharps and flats are indicated as usual with # and ♭.

2. The windchest

Introduction

The windchest is a core part of an organ, holding the pipes in place and controlling the air channelled through them.[18] The aims of this chapter are:

- to briefly analyse the original windchest of the Silberne Kapelle organ, its building methods, and its limits;
- to suggest an alternative solution (based on historical models), showing its advantages;
- to explain how only a few rules are enough to build such a windchest, and how to manage with them.

As George A. Audsley has written in his book *The Art of Organ-Building*, it is

> extremely difficult to have every detail absolutely satisfactory, for it has been found, from practical experience, that perfection in one direction is unfortunately accompanied by some imperfection in another. This may be accepted as a general rule in organ building, and in no branch is it more marked than in that of wind-chest construction.[19]

2.1. The windchest of the organ of the Silberne Kapelle

Considering what Audsley wrote, our first step is to look inside the organ of the Silberne Kapelle to see how the original windchest was made. It was carved out from a solid walnut plank: channels (grooves) were carved using a chisel.[20]

The restorers had plenty of doubts both in 1944 and in 1949: they judged it negatively. Effectively, they found a bent (deformed) board, which consequently compromised the airtight on both sides. Their last choice was to maintain the main board of the windchest, newly making it flat.

2.2. Which windchest for an early-modern organ?

My priority is to obtain the most stable windchest, which significantly affects the quality of sound and the stability of tuning; considering that a modern organ has to withstand

18 For a general description of the windchest and its working principles, see for example Ole Olesen et al., "Orgel", *Die Musik in Geschichte und Gegenwart*, https://www.mgg-online.com, or Barbara Owen, "Organ", *Grove Music Online*, https://www.oxfordmusiconline.com, accessed 17 December 2019.

19 George A. Audsley, *The Art of Organ-Building*, New York: Dover Publications, 1965: 196.

20 See Donati, *L'organo*, 2006.

modern heating systems and extremely dry rooms, which affects the grooves of the windchest, I opted for a building method which can be defined as "historically plausible" for the sixteenth century, even if not used in the windchest of the Silberne Kapelle organ. This choice will make a difference to the windchest's stability without affecting the authenticity of the process.

Instead of carving grooves directly into a solid plank of walnut, as in the Silberne Kapelle organ, I used wooden bars to form the grooves into a frame. This is the so-called bars and sliders windchest, which has been made unchanged for about six hundred years. There have been minor changes in the materials and technological solutions for sealing, but the stability of this system is notable: the bars create a stable network of solid wood.

More specifically, I based my version of the windchest on the one admirably illustrated by Dom Bedos in *L'art du facteur d'orgues,*[21] in which one see that the bars forming the wind-channels (grooves) are securely glued into sinkings cut in the front and back cheeks of the frame, and the end pieces are tenoned and mortised in the end of the frame (see Fig. 2.1).

2.3. How to cover the grooves

When grooves are carved out from a solid plank, like in the original organ, three sides are delimited by wood. But if the grooves are formed by two lateral bars, the top of the network must be covered. Regarding the covering board (on which the stop sliders rest), one technique is given by Dom Bedos (see Fig. 2.2). As visible in the central picture, his table is formed of narrow strips of hardwood, well glued to the frame and bars, being jointed and securely pinned.

The critical point of this method again relates to modern heating systems and dry rooms. Its origin is given by the crossed directions of grains: bars run vertically, and the covering board runs horizontally. Experience has shown that the force applied by the top table to the bars – during contraction/expansion in a dry/wet climate – can be so strong as to bend the bars. Bent bars create problems both on pallets and sliders, which no longer lie on a flat surface.[22]

The method I developed is a variant of Dom Bedos' method, in which I modified the top board, to avoid the inner tensions that result from crossed grains. My method is also compatible with early building techniques, simpler for one working man, and specifically developed to facilitate the use of hide glue only. Here is a description. Instead of applying long wooden strips perpendicular to the bars, as Dom Bedos suggests, I prepared six smaller quarter-sawn panels as long as the bars (570 mm), about 300 mm wide and 7 mm

21 Dom François Bedos de Celles, *L'art du facteur d'orgues,* Paris: L.F. Delatour, 1766–1778.

22 A modern solution that avoids this problem would consist in gluing a sheet of plywood to cover the grooves (no matter the grain direction); of course, modern technology is needed here: first to create plywood, and then to glue a sheet of that size all at once. The last step requires a large pressing machine and long-open-time glue.

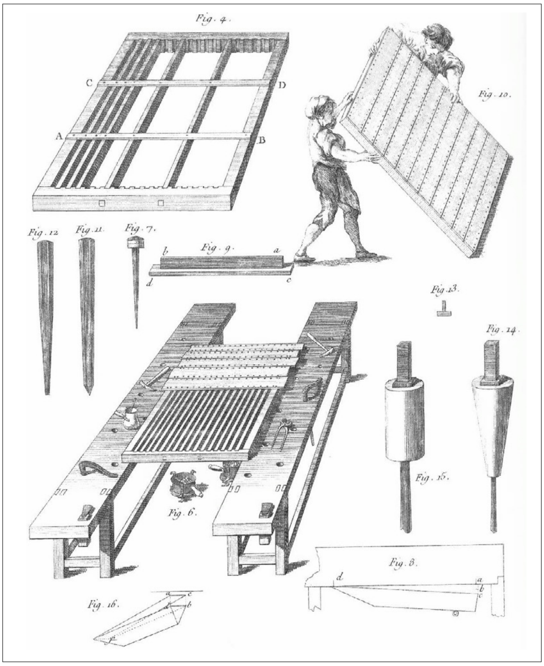


Figure 2.1

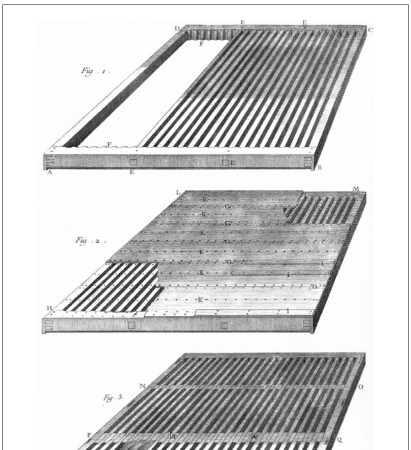


Figure 2.2

thick; indicatively, each panel covers about 10 grooves. The aim is to set the direction of the grains, when glued, concordant to the bars. I also prepared five special bars, partially slotted along the main direction at a certain depth; this action adds a special propriety to the bars: they become sligtly elastic with respect to the later forces, but at the same time, they maintain the stability along the main direction. Then I glued together the frame's cheeks (which delimit the windchest) and I glued inside the five slotted bars (see Fig. 2.3).

Each pair of the six panels is jointed across the slotted bar, but at a gap of a few milimetres (see Fig. 2.4, which shows two panels before being glued to the central slotted bar).

In order to do that, before gluing them, they must be precisely cut to their final dimensions and temporarily held in position by a few wooden pins. The slot remains partially visible between the two consecutive panels.

Taking into account that hide glue's open time is only ten to twenty seconds (one must not let glue gel before applying clamps), I glued the first panel to the frame: see Fig. 2.5. A "mask" board covered with paper helps to uniformly distribute the clamps force on the whole surface.

Meanwhile, I set and glued the other bars within the panel: see Fig. 2.6.

Each panel and its bars required one day for me to assemble, mainly because I worked with few clamps and only one mask board, and I waited for the glue to set firmly. The modern method described in footnote 22 would require 30 minutes to glue all bars and the plywood panel; the ancient method took to me a couple of days. The last step of this slow process is visible in Fig. 2.7.

Figure 2.3

Figure 2.4

Figure 2.5

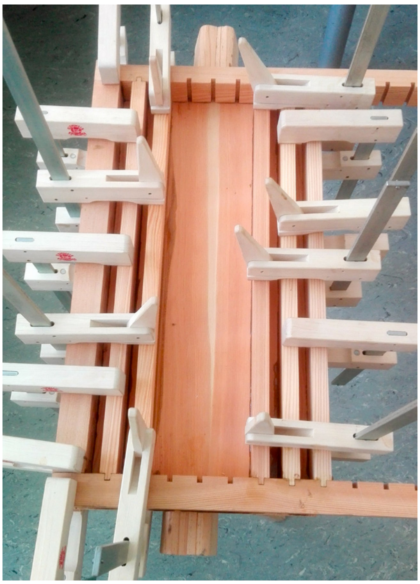


Figure 2.6

Figure 2.7

I inserted a thin strip of wood (larch) into the lower side of the windchest to receive the pallet hinge (see Figs. 2.8 and 2.9 for the clamping techniques); the strip also delimits the portion of channels, which will be closed by pallets. The portion of the channel which extends beyond the pallet-box will later be closed by gluing strips of paper.

Since a perfect flatness is highly important for both sides, I used a very smooth planer to correct imperfection (see Fig. 2.10).

Despite the simple building method, I was satisfied by the level of flatness achieved: see Fig. 2.11, which shows the grooves, and Fig. 2.12, which shows the six panels on top.

2.4. On the behaviour of this flexible structure in the dry climate of Munich

Fig. 2.13 shows clearly the effect of the dry climate on the windchest, showing how it reacts under humidity/temperature changes. I cut panels to the final measure in my workshop in Italy, where humidity is between 50 % and 60 %, with a temperature maximum of 25° (it was late June). The gap between two of them was as large as the small piece of wood in the picture: namely 2 mm.

Despite using well seasoned quarter-sawn larch, after two months in Munich, in a room with 32° during the day and less than 20 % of humidity, significant contraction in

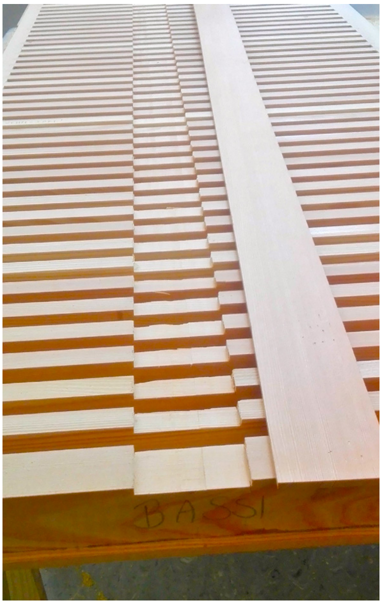


Figure 2.8

Figure 2.9

Figure 2.10

Figure 2.11

Figure 2.12

Figure 2.13

the panels was evident, so that the gap was approximately twice as large by late August. The elasticity of the slotted bars locally absorbs the contraction, avoiding cracks in the panels.

The windchest is now in Italy, and in November, the gap became somewhat less, the humidity being 40 % with a temperature of 21°. Even if the change was not perfectly reversible, the interspace between adjacent panels is now less.

2.5. Pallets

Since all windchest channels are identical, from basses to trebles, and their width is 15 mm, pallets must likewise be identical and have the same width: 20 mm, accordingly with the general golden rule which adds 5 mm to the channel width (2.5 mm to the left and to the right). This is consistent with the measures taken from the Innsbruck organ. This choice gives a good lay surface, wide enough to ensure a safe airtight and not too big to create excessive "top resistance".[23]

All pallets are 180 mm long and 18 mm thick. The typical triangular shape reduces the pallet mass and the torsion forces. At the same time, it increases the wind-way between pallets to allow the maximum lateral air flow when a pallet is open. Perfect flatness is the most important quality for a pallet, so I opted for fir-wood because of its stability, taking care to select fine-grain and quarter-sawn pieces only (Fig. 2.14).

Fig. 2.15 shows how to prepare oval handmade eyes (for a pull-down action), and how to stick them in the pallet.

It is notable that the same handmade eyes are applied to the keys (as visible in Chapter 4, Fig. 4.21).

As an alternative to this simple historical technique, small screw eyes or pallet hangers (see Fig. 2.16), manufactured by modern technological methods, could be used.[24]
Each pallet is leathered with two layers of first-quality sheepskin,[25] which guarantees the best airtight as shown in Figs. 2.17 and 2.18. As visible, the leather exceeds the pallet length on the rear part to create the pallet hinge. To increase the stability with respect to the torsion, a second strip of leather was glued on top.

This method is well described by Dom Bedos in his treatise (Fig. 2.19).

23 "Top resistance" refers to the nature of the touch of a mechanical organ. By pushing the key, the organist feels the equivalent of the plectrum plucking the string of a harpsichord. This action is related to the pressure difference across the closed pallet. Top resistance must be consistent with the elasticity of the mechanical action, to guarantee the simultaneous movement of key and pallet, which is what provides the possibility to influence the sound attack.

24 This is a good example of how modern practices are sometimes unnecessary (why should one unscrew hooks from pallets?) and would mean a deviation from the historically accurate reconstruction process.

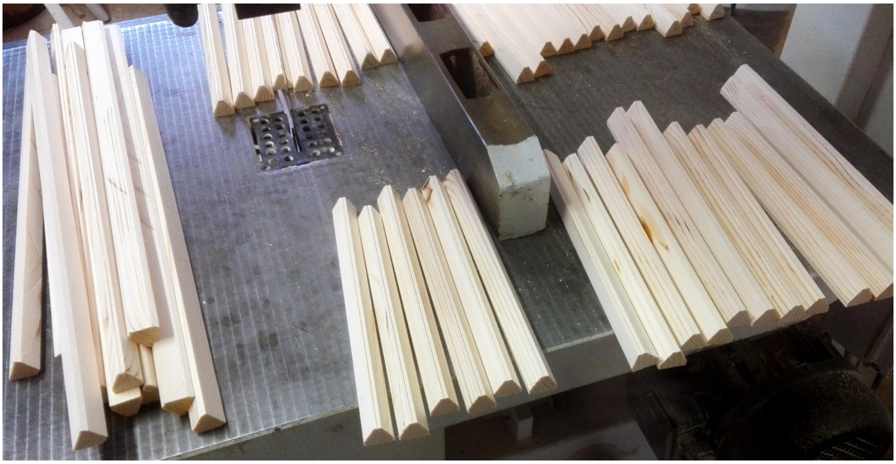


Figure 2.14

Figure 2.15

Figure 2.16

2.6. Leather purses

The so-called “pull-downs”, which are hung on the pallets, pass through leather purses, which hold the airtight of the pallet-box: see the sketch in Fig. 2.20. Each purse has two eyes: one linked to the pallet, the other to the key action.

Figure 2.17

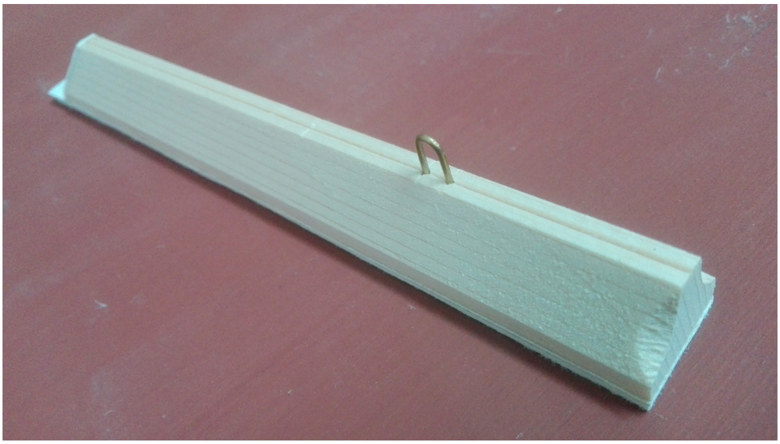


Figure 2.18

25 For the leather for organs see Kristian Wegscheider, Bernhard Trommer, and Michael Wetzel, “The use of leather in modern organ construction”, *ISO Journal* 31 (2009): 7–38.

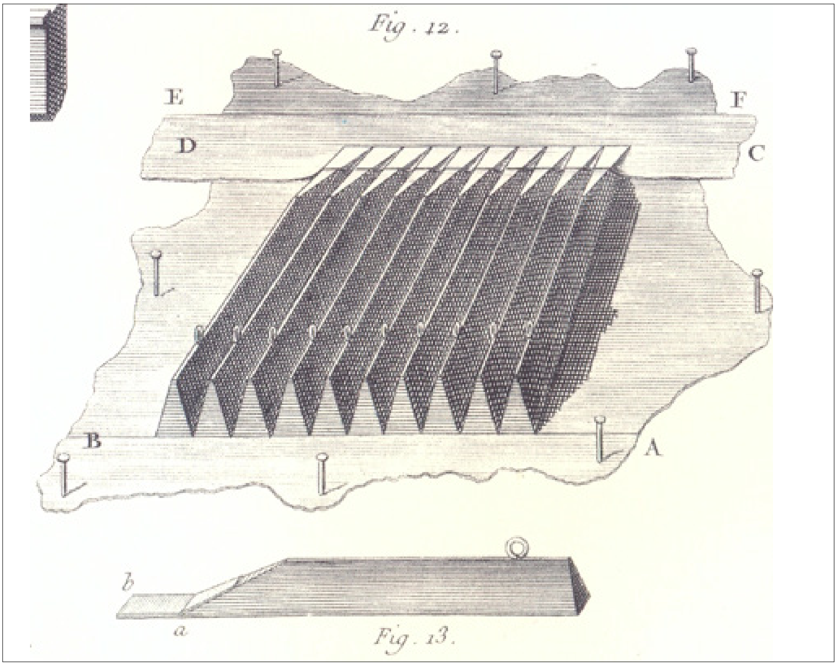


Figure 2.19

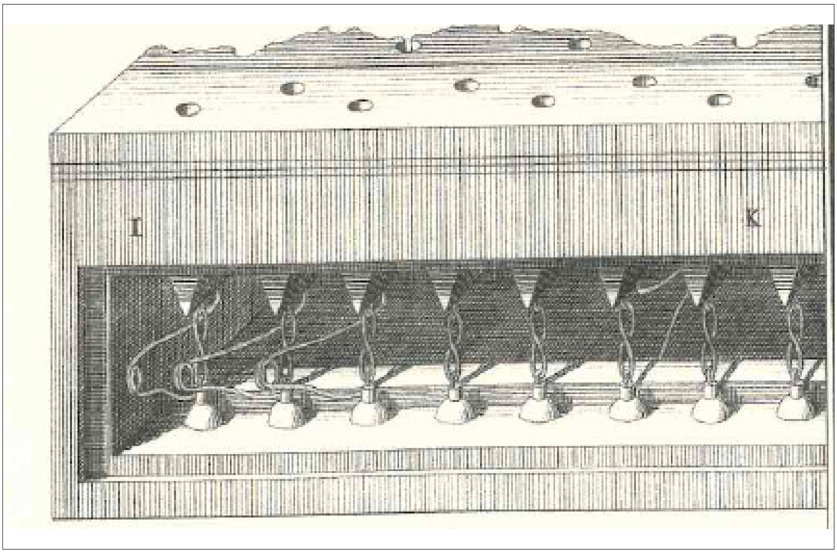


Figure 2.20

Leather purses are cut from top-quality lambskin into square pieces (Fig. 2.21). I developed a specific tool (see Fig. 2.22) to shape each purse, by pressing a piece of soft lambskin into a mould.[26]

A good deal of care was required, since the lambskin can be ripped. First I wetted the leather, so that the fibres could be easily extended and the "cup" shape well maintained after drying.

Before extracting the purse from the mould, the centre of the purse is pierced to allow the pull-down wire to pass through (Fig. 2.23).

The flat rim or flange is subsequently trimmed round (see Fig. 2.24) and they become like the ones shown in Fig. 2.25.

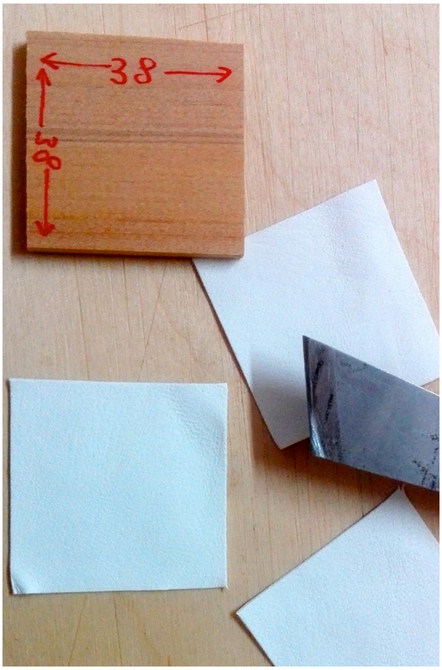


Figure 2.21

Figure 2.22

26 A simpler method would also be possible; it involves gluing a strip of sheep leather across the holes in the bottom board of the pallet box. With a rounded hand tool, one shapes each purse by depressing it into its own hole. For the pull-down wire, the procedure is the same as above.

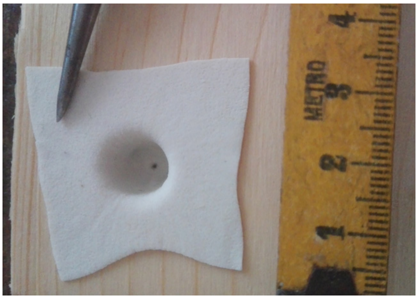


Figure 2.23

Figure 2.24

Figure 2.25

Figs. 2.26 and 2.27 show how to make the eye using a pair of round nose ribs and a brass wire (diameter 1.25 mm).

Two small leather washers are trimmed and glued across the purse for the best mechanical coupling between wire and purse: see Fig. 2.28.

Finally, the purses reach the form shown in Fig. 2.29.

The next step consists of gluing the purses, around the flange, to the bottom board of the pallet-box, one by one. A jig was developed to make adjustable S-shaped hooks which link the pallet and the purse eyes. Fig. 2.30 shows the pallet-box equipped with the first pallet.

Figure 2.26

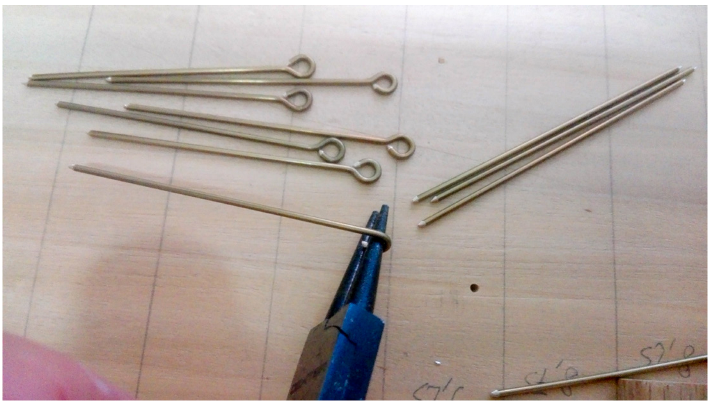


Figure 2.27

Figure 2.28

Figure 2.29

Figure 2.30

2.7. How to design a windchest using only a ruler and a square

As explained in my Introduction, I did not create a 1:1 scale plot for the windchest: on the contrary, I worked on the windchest surface directly. Since the windchest is made of four layers, the first step is to stack them and keep them in position by means of pins.

More specifically, I first arranged the stop sliders on the surface of the windchest's frame (called the lower board; see Fig. 2.12): a square is the main tool for that, as shown in Fig. 2.31.

Then I placed the so-called upper board, a walnut panel, on the sliders, as shown in Fig. 2.32.

The upper board will be the external surface of the windchest and serve as the base for the pipes. It is divided into three long parallel strips to make it more stable. On the upper board, I placed six pieces of cardboard to exactly cover the walnut surface; these pieces of cardboard must be especially strong since it will act as the rack-board.

As shown in Fig. 2.33, the pipes are arranged on the cardboard surface according to their dimensions and the order of the channels. The exact position of each pipe and its shadow are marked down on the cardboard.

This is one of the most crucial moments in the whole building process; the most elegant pipe disposal must be achieved, so that each pipe can speak freely and receive sufficient wind. Likewise, the feeding of the pipes in the facade must be simple and natural.

Fig. 2.34 shows how the cardboard surface appears when all pipes are marked down.

The yellow lines represent the channels used to feed the facade. The channels will be carved into the walnut panel, as explained later.

Figure 2.31

Figure 2.32

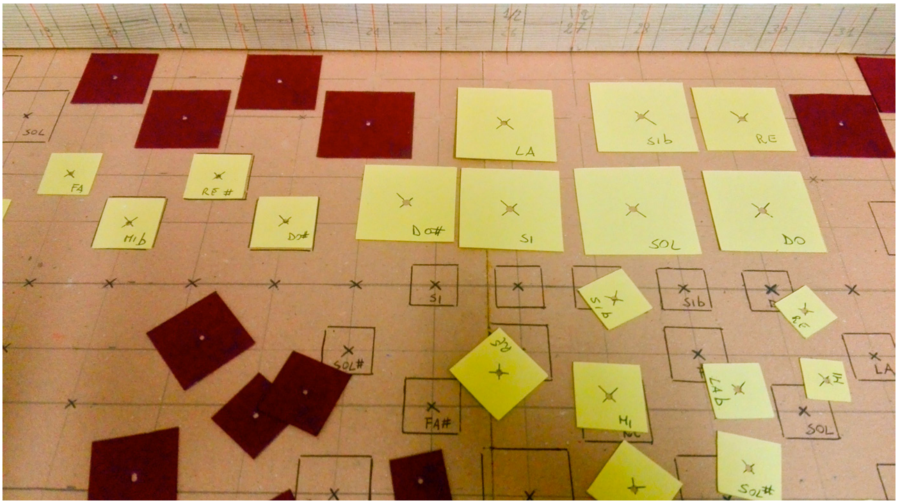


Figure 2.33

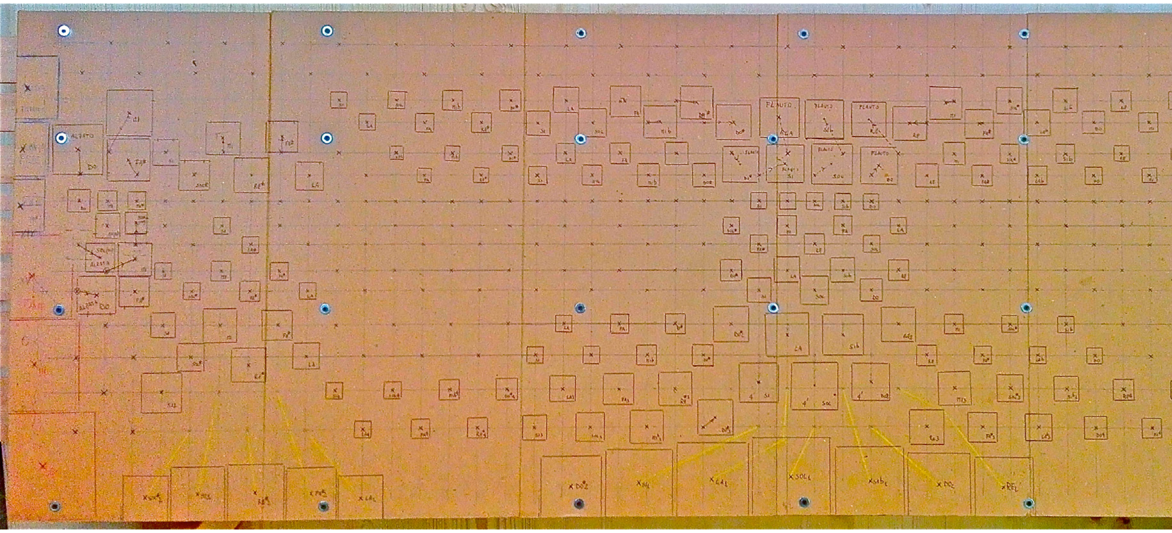


Figure 2.34

2.8 The windchest in the making

Once every pipe and every detail is checked, the steps are as follows.

Step 1:

- Trim out the cardboard to open square holes according to the pipe dimensions (Fig. 2.35).
- Drill all layers together from the top to the bottom. The diameter of the holes is chosen to guarantee the correct air supply for the pipes: the reference is the original windchest of the Silberne Kapelle organ.
- Finally, separate the layers and clean up the holes.

Step 2:

Considering the lower board of the windchest again, the next step is to create V-shaped channels across the pipe holes in order to prevent any running of the wind when the slider is not drawn. The channels are shown in Fig. 2.36.

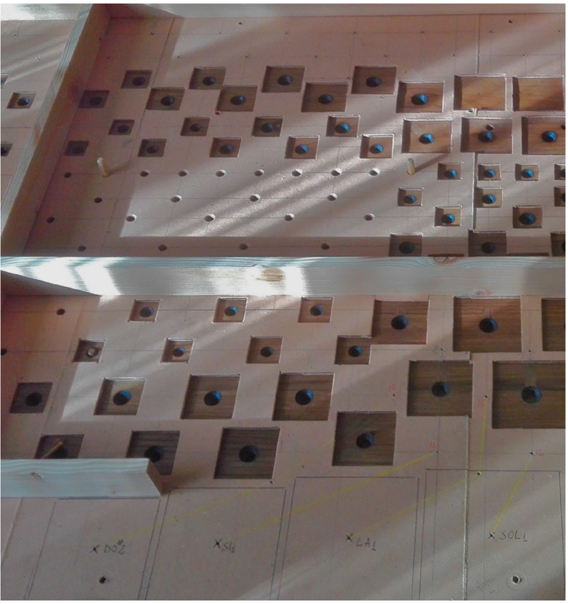


Figure 2.35

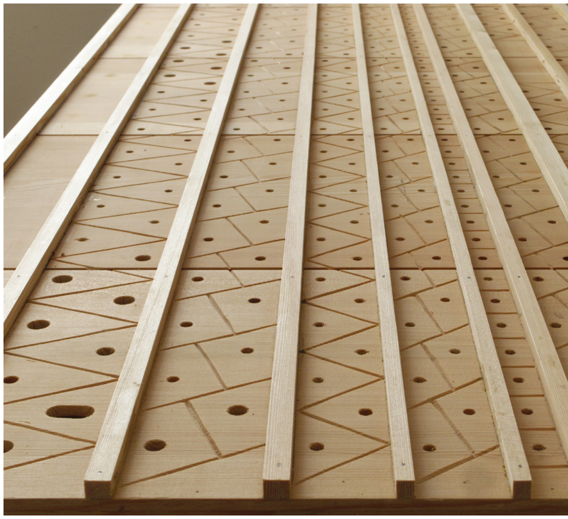


Figure 2.36

Step 3:

As shown in Fig. 2.36, in order to drive the sliders, several bearers were applied, side by side. The thickness of the bearers must be carefully calibrated to relieve the sliders of any undesirable pressure from the upper board, and to allow for their easy movement by the draw-stop action.

Step 4:

Under the top walnut panel, I glued a washer of lambskin, which creates a less rigid surface, ensures a good sealing with the sliders, and creates a way for air to escape.

Step 5:

The channels corresponding to off-pipes are carved out to match the yellow lines marked on the cardboard. Figs. 2.37 and 2.38 show the method used to cover the channels after being carved.

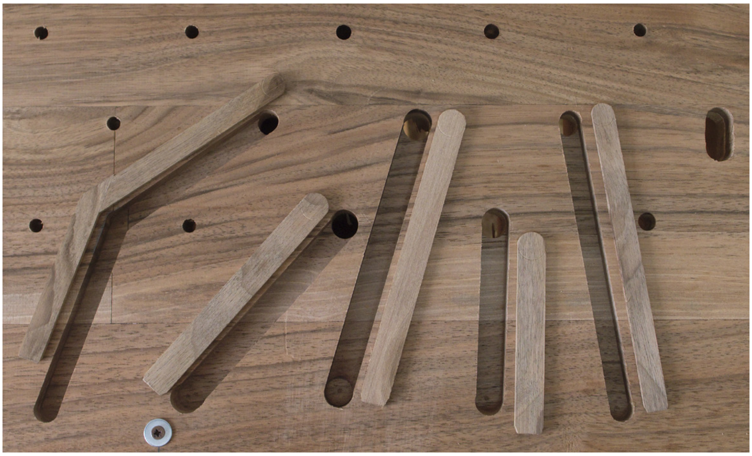


Figure 2.37

Figure 2.38

Step 6:

Every hole on the top surface of the upper board is burned by means of a cone, as in Fig. 2.39. In this manner, the toe of the pipe's feet fits perfectly into the conical shape produced by the burn.

Step 7:

Following tradition and the technology of that time, I pinned down the upper board utilising the pins shown in Fig. 2.40. Leather washers and beeswax help in case the pins must be pulled out.

Step 8:

The cardboard used to form the rack-board is reinforced by a wooden network, shown in Fig. 2.41. The rack-board is supported by a few pillars.

Step 9:

The windchest was equipped with pallets, springs, and leather purses; the pallet-box was assembled and closed.

Conclusion

At the end of this process, the windchest is as shown in Fig. 2.42.

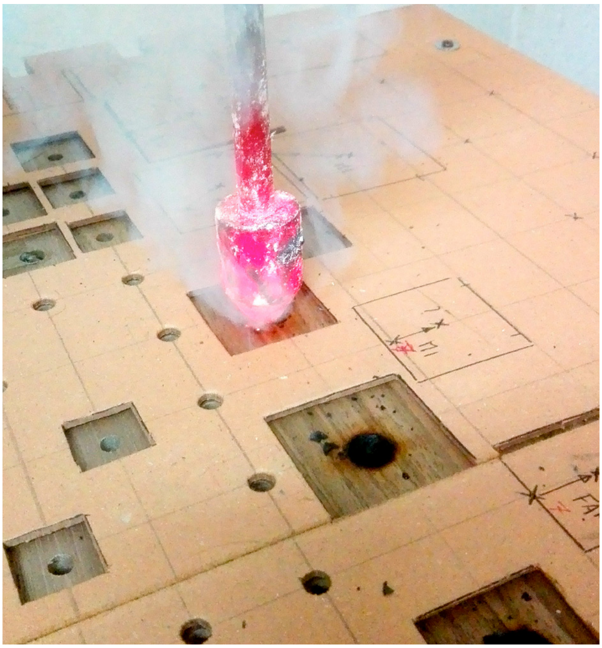


Figure 2.39

Figure 2.40

Figure 2.41

Figure 2.42

3. The bellows

Introduction

Considering the reshaped lower half of the organ-case, I developed two wedge bellows with five ribs which fit perfectly into the space behind the pedal, as far as the rear panel. Since we have no evidence about how the original bellows were accommodated inside the case, or how many there were, I opted for a crossed stacking. Similar solutions can be found in small positive organs, where the relationship between available room and bellows volume is quite critical.

3.1. How bellows operate

The two bellows alternate: as one acts as a reservoir, the second one can be lifted up to be filled. The bellows are pressurised by bricks.

Each bellow operates by a lifting mechanism consisting of a rope wrapped on a wooden roller. The roller is integrally connected to a wheel, which turns by means of a second rope, actioned by hand. At the time of writing, this mechanism is not yet built; it will be placed on the top of the lower case, behind the top one. No escaping valves are then necessary.

3.2. Bellow boards and filling pallets

The dimensions of the four boards (upper and lower leaves) used to make bellows are 1200 × 600 × 20 mm, so the ratio between sides is 1:2.

In the lower leaf I created three holes: the square hole (100 × 100 mm) is for the wind-trunk, and functions as output; the other two are filled holes, regulated by a double-filled pallet shown in Fig. 3.1; it presents two wings hinged to a central rib. The

Figure 3.1

thickness of wings becomes progressively thinner to reduce the torsion and the weight. For similar reasons I chose rift-sawn fir-wood. This model is based on the historical one shown in Fig. 3.2.

The filling pallet action is essentially determined by the difference of pressure across its surfaces. During the filling cycle, the pallet is lifted by the atmospheric pressure (sucked inside), so the air passes through the filling holes.

As the upper leaf is released, the pressure inside the bellow increases to the final level and it presses down the two wings of the pallet: the holes are suddenly stopped and perfect airtight is achieved.

3.3. The bellows' ribs and leathering

Ribs comes from good-quality quarter-sawn fir-wood, combining their triangular shape in a rectangle in order to save wood. The two longer edges of each rib are rounded. Fig. 3.3 shows a few ribs painted with the typical red varnish.

The ribs are first joined in pairs with a sheepskin strip along the centre, about 15 mm wide (Figs. 3.4 and 3.5).

In Fig. 3.6 I am cutting strips from a top-quality sheepskin. On the inside they are jointed by gluing a cloth tape strip, about 15 mm wide, going right up to the ends, but not skived.

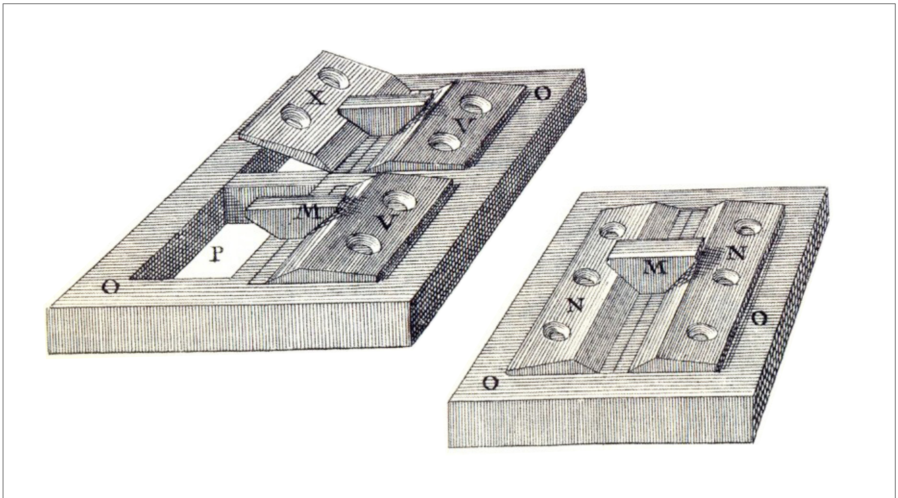


Figure 3.2

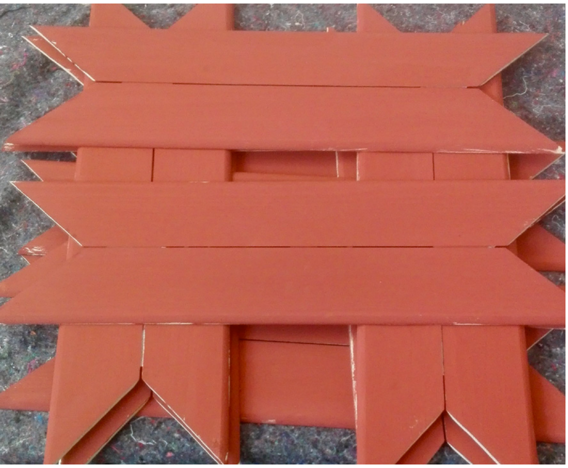


Figure 3.3

Figure 3.4

Figure 3.5

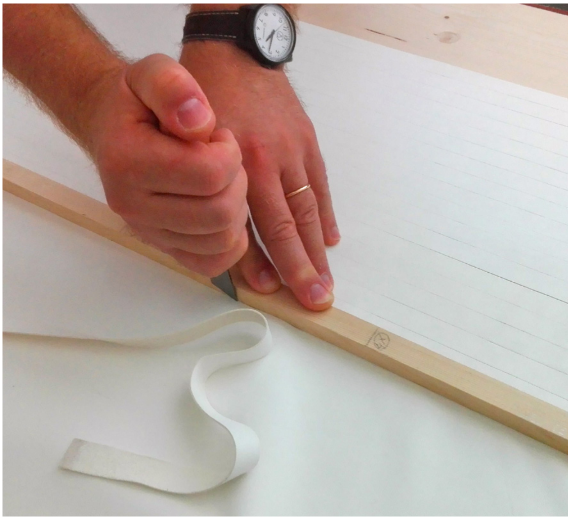


Figure 3.6

The five pairs of ribs are jointed together and cloth tape strips are glued to the inside edges, as shown in Fig. 3.7.

The edges of the boards (upper and lower leaves) are not rounded: ribs are glued on the surface, about 10 mm inside from the edge. The ribs are laid first on the lower leaf (see Fig. 3.8) and are held in position on the long sides with three pins.

3.4. How boards are hinged

The upper and lower leaves are hinged as follows: a strip of wood is glued to the bottom of each leaf (see Fig. 3.9). The thickness of the strips is carefully calibrated to be equal to the thickness of the ribs.

The role of these strips is quite relevant, as they ensure the flatness of the two leaves and work as a hinge. Along the edges where the two strips are in contact, I first glued a strong cloth strip: this is the first step necessary to create the hinge.

Since during the working cycle the force which tends to separate the hinge becomes a significant factor, it is a good rule to bind parts using a rope; this method is clearly explained in the Dom Bedos treatise as shown in Fig. 3.10. It is also similar to the techniques used to bind books. Fig. 3.11 shows the result.

Figure 3.7

Figure 3.8

Figure 3.9

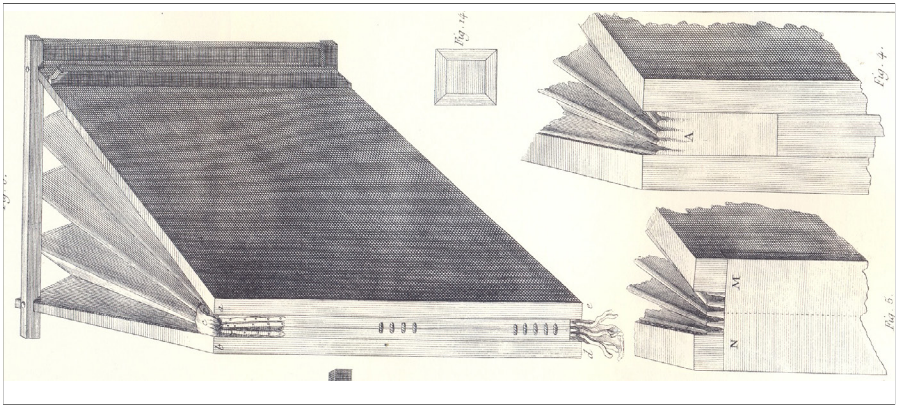


Figure 3.10

Figure 3.11

3.5. Gussets and butterflies

As shown in Fig. 3.12, gussets, corners and butterflies are finally glued. For convenience, parts are glued when the bellow is open at its maximum angle, which corresponds to the maximum extension of leather parts.

In particular, the cut circles of Fig. 3.13 reinforce every corner of the ribs.

I carefully covered the corner with a second layer of thin sheepskin to prevent any leakage: see Fig. 3.14.

The hide glue reveals all its advantages here, as discussed in Appendix A6. The most important advantage is its initial sticky action, which is very useful for quickly setting leather parts.

Fig. 3.15 shows one of the two bellows ready.

Figure 3.12

Figure 3.13

Figure 3.14

Figure 3.15

4. The keyboard

Introduction

The keyboard is the most important mechanical part of an organ. It represents the interface between organist and organ. The evolution of the keyboard, from stud buttons or large keys for two fingers in the Middle Ages to the modern piano-like keys, is strictly connected with musical goals as well as with current technology.

In this chapter I will describe my reconstruction of an early-modern keyboard based on the original keyboard of the organ of the Silberne Kapelle. My approach is based on proportions as well as on the early technology available at that time. By using proportions, my aim is not only to replicate the keyboard, but also to understand the shape of the keys. The building method and the early technology involved (including tools) are strictly connected to the final result: for example, the interspace between keys will result from the building process itself.

The sixteenth-century organ of the Silberne Kapelle has a four-octave keyboard, with a short first octave, as was usual at that time. Of all the measurements, the most relevant is the distance between the left edge of Do and the right edge of Si within the same octave. This value is 168 mm. With a simple calculation, as confirmed by measures, the whole extension of the keyboard over the four octaves is confirmed as 648 mm.

Fig. 4.1 shows a modern approach to describing the keyboard; it consists of a detailed numerical depiction of the manufactured keyboard, in which each key is drawn as a single piece. Every corner is precisely measured, included the intrinsic inaccuracy due to the handmade nature of the product. (For reason of clarity, I used average values calculated over several keys.)

Using this approach – which is perfect for making a copy using computer numerical control (CNC) machinery – understanding the idea behind the keyboard is difficult.

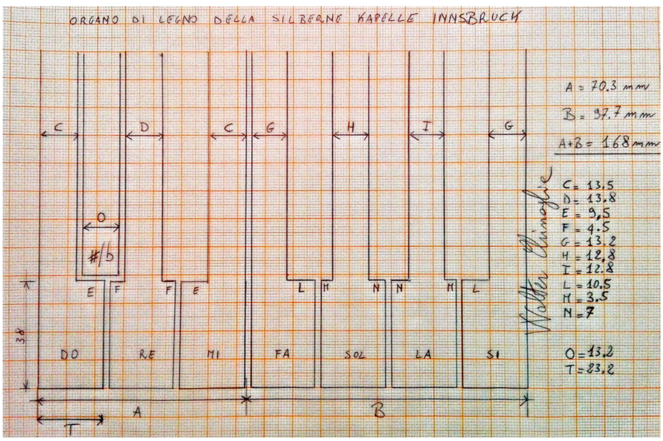


Figure 4.1

Comprehension is not the aim of this method, which is merely descriptive. Inaccuracy in key shape in the original manufactured keyboard cannot be distinguished by intentional key shaping. A blind copy of a keyboard is less interesting than one that is rebuilt after deep comprehension of the original.

The ancient alternative to the method above is founded on proportions, which are at the base of any antique building process. In Appendix A4, which is dedicated to proportions, is an image (Fig. A4.1) which shows how one octave is dived into keys using only a pair of proportional dividers (Fig. 4.2), with no absolute measurements. Equivalently, the procedure described below starts with the creation of a ruler for the keyboard.

4.1. The creation of a ruler

The first step to make a keyboard is to build a ruler, made from a thin strip of larch (or similar light-colour and fine-grain wood, approx. 700 × 60 × 3 mm). A portion of the ruler described below is shown in Fig. 4.3.

I indented a line across the strip from side to side, at half-width. This line delimits the diatonic portion of the keys (bottom part) from the chromatic one (top part).

Using the original keyboard of the organ of the Silberne Kapelle as a reference, I marked on the ruler the compass of the keyboard, which corresponds to 648 mm in our modern measurement system. Similarly, I marked the portion Do–Si (168 mm). To do that, as usual, I used a marking tool and a small square.

Starting with the portion Do-Si, which defines the octave, I divided it in seven equal parts, and indented accurately each diatonic key (the bottom part only). Subsequently, I indented divisions between Si–Do and Mi–Fa, all across the ruler. Do1 and Do5 are also marked.

For the chromatic keys, i.e. the top part of the ruler, I divided the portion Do–Mi into five parts, while the portion Fa–Si was divided into seven parts.

Finally, the centre of each key was marked and a small hole (1.5 mm) was made.

This ruler contains all the information one needs to make a copy of this keyboard.

4.2. The keyframe

The keyframe which supports the keys is constructed out of solid larch, jointed, and securely glued in the corners. Fig. 4.4 shows it still under construction. Commonly in old organs, keys are pivoted at their rear end, so that the keyframe shows a back-rail which holds the pins on which the keys rock.

The mid-rail is a strip of solid wood which holds mid-pins, which pass through the centre of the keys. A slot is cut in the key body to allow it to move freely.[27] The so-called bed-rail arrests the descendent of the keys; it is padded with thick felt.

27 Slots retain keys in position so that they do not rub against each other when they move. Further details about slots are given in section 4.6.

Figure 4.2

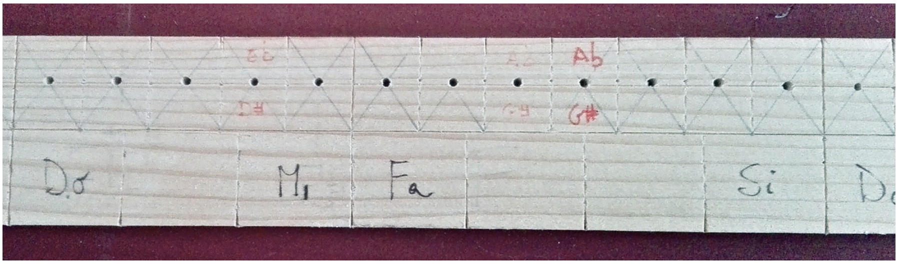


Figure 4.3

Figure 4.4

4.3. The plank

The first step here was to glue together several pieces of well seasoned wood, forming a perfect flat plank; its length, measured across the grains, must be slightly greater than the compass of the keyboard. I chose to use lime: it is a very stable wood, easily workable, and when thoroughly seasoned and dried has no tendency to wrap or twist.

The plank was cut to the final measure, corresponding on one side to the length of keys, and on the other side to the compass of the whole keyboard.

Meanwhile, I selected a log of the finest-quality Italian boxwood to cover the keys (see Fig. 4.5).

Fig. 4.6 shows the log cut in two halves, while Fig. 4.7 shows it reduced to slices.

As shown in Fig. 4.8, the frontal part of the plank was dressed with boxwood (already at its final thickness).[28] The most desirable position for the junction between consecutive boxwood plates is where the keys will be separated by cutting.

Three cross-grooves are also marked deeply, both to delimit the diatonic portion and for aesthetic reasons.

The upper surface of the plank was accurately divided and marked according to the keyboard ruler. The position of every pin was always accurately marked.

4.4. Making holes for pins

After that, I temporarily jointed the plank to the frame using a few extra pins (removed at the end of the process).

I subsequently drilled holes where the pins will be inserted. Both plank (keys) and frame are now pierced: see Fig. 4.9.

Having separated the keyframe from the plank, I fitted the pins into the keyframe. Mid-pins are longer than the ones used as a pivot at the rear.

Figure 4.5

28 The original overlay is ivory (today forbidden). My choice of boxwood was made in accordance with early sources on Italian organs.

Figure 4.6

Figure 4.7

Figure 4.8

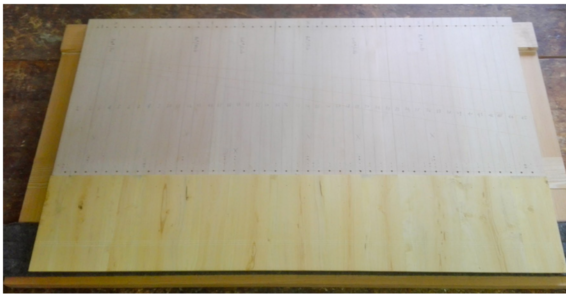


Figure 4.9

4.5. Cutting the plank

It is now time for the plank to be cut: I sawed it starting from the rear edge, as shown in Fig. 4.10, which also shows the first cut along a straight line.

Then, I cut the portions shown in Fig. 4.11, which correspond to the sections Do–Mi and Fa–Si, i.e. where the keys go straight. Do1 and Do5 are also sawn individually.

Considering now two adjacent portions, namely Do–Mi and Fa–Si, Fig. 4.12 shows how I divided the diatonic keys. In doing that I used proportions 1/3 and 1/4 respectively.

By cutting keys using a specific bandsaw blade, the interspace between two adjacent keys is done automatically: it corresponds to the thickness of the cut. I used a blade with very fine teeth and almost no setting.[29]

It was then time to cut the rear part of the keys. Fig. 4.13 shows how to proceed with the bandsaw (from the external key first, to the internal one), while Figs. 4.14 and 4.15 show the two portions Do–Mi and Fa–Si already cut into five and seven parts respectively.

To separate each key from the adjacent ones, I drilled close holes (2 mm diameter, as in Fig. 4.16) and then cut away parts using a fretwork saw with a fine blade.

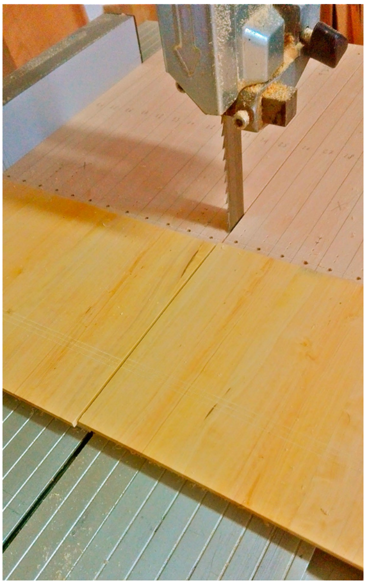


Figure 4.10

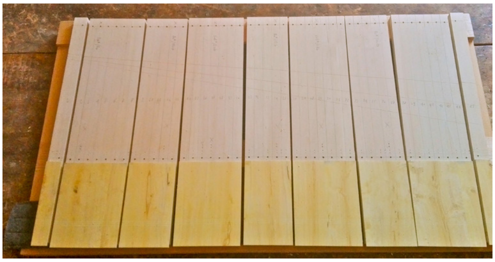


Figure 4.11

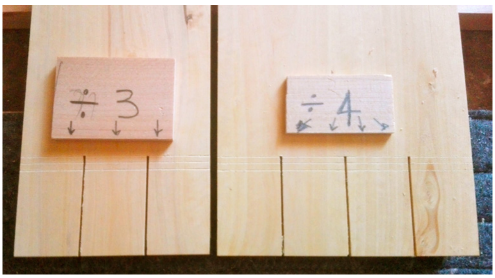


Figure 4.12

29 For more puristic readers, I would point out that a Japanese hand saw could be a valid alternative to a bandsaw.

Figure 4.13

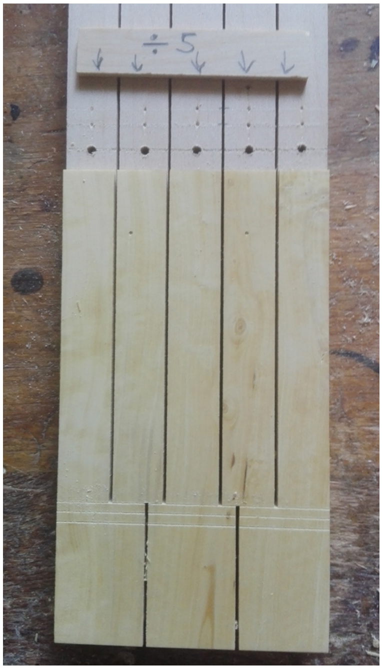


Figure 4.14

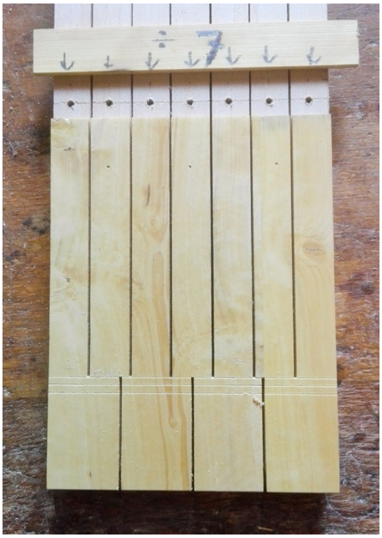


Figure 4.15

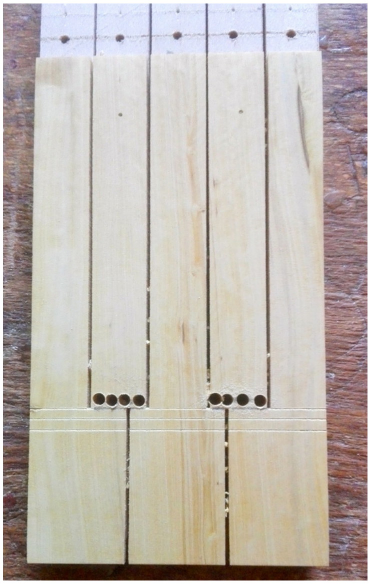


Figure 4.16

4.6 Making a slot in the key bodies

Before setting keys in their definitive position, a slot in the centre of the key bodies and a triangular hole at the rear ends are necessary, to make them rock-free. To do that, I developed a specific tool, shown in Fig. 4.17. It consists of a small blade (shaped as the final slot) fixed on a long metal handle.

Putting the blade on a flame, so that it reaches a high temperature and is coloured red, means that it gains enough energy to burn the wood locally. Slots are thus easily created, without stress grains on the key wood. The process is show in Fig. 4.18.

4.7. The split keys

Subsemitones often appear in the organ repertoire during the sixteenth and seventeenth centuries. They make it possible to use the organ to accompany voices and other instruments. The most common and most useful are Re#/Mi♭ and Sol#/La♭, so this was my choice. Moreover, I introduced a split key in the lower octave in order to have Fa#, which is normally lacking in short octave configuration. Concerning split keys, Figs. 4.19 and 4.20 show two historical keyboards with split keys:[30] Fig. 4.19 is the famous organ by Lorenzo da Prato (1471–75); Fig. 4.20 is the organ by Baldassare Malamini (1596). Both are in the church of S. Petronio (Bologna, Italy).

As clearly visible, the main difference is in the plane of cutting: in the organ by Prato the key body was cut horizontally, while in the other organ the cut plane was vertical. In my organ, I opted for the first solution, for two reasons:

- The method was preferred also by Antegnati (e.g. in the organ of the Basilica Palatina of S. Barbara, in Mantova, Italy).
- By cutting the body of the key along the horizontal plane, the key width is unaffected, which results in a stronger and more stable key lever.

Fig. 4.21 shows the split keys on my keyboard.

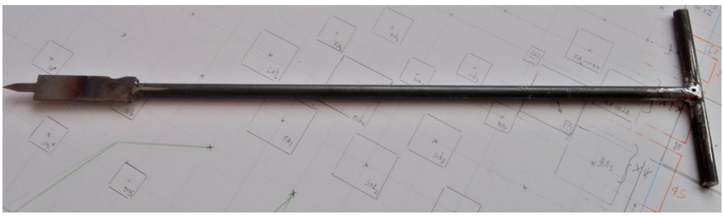


Figure 4.17

30 Reproduced from Liuwe Tamminga, "Strumenti', http://www.liuwetamminga.it/strumenti.html, accessed 31 August 2019.

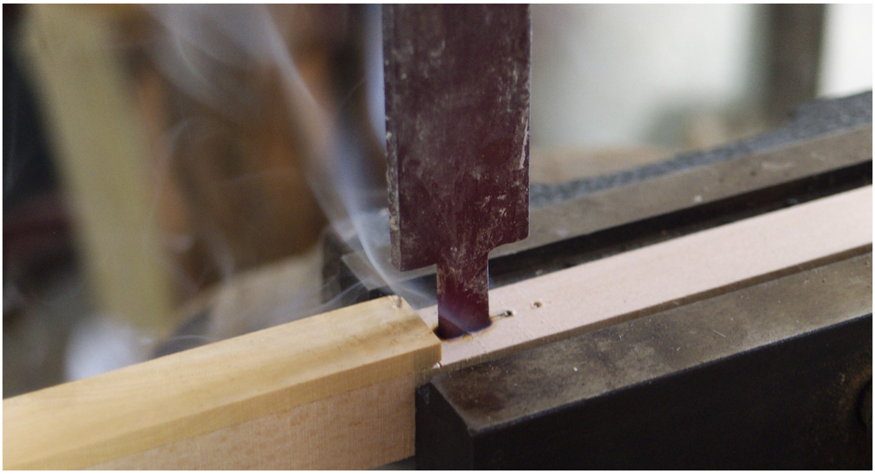


Figure 4.18

Figure 4.19

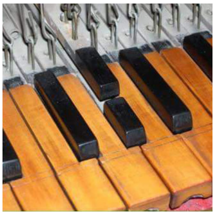


Figure 4.20

Figure 4.21

4.8. The fronts

I created a special drill bit to mould the fronts of the natural keys (made of straight grained boxwood), as shown in Fig. 4.22.

Then these fronts were glued to the natural keys (Fig. 4.23).

4.9. The eyes for keys

The trackers are linked to the keyboard by brass eyes, made in the same manner as the eyes for pallets (see Chapter 2, Fig. 2.15). In the case of the split keys, the eyes of the lower key come through the upper one. The two eyes are aligned.

Fig. 4.24 shows the keyboard with all parts already assembled. (The two lateral cheeks are not yet done.)

Figure 4.22

Figure 4.23

Figure 4.24

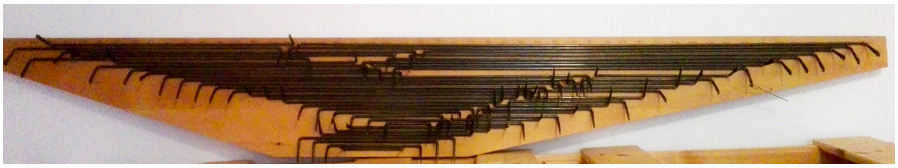
5. The rollerboard

Introduction

In this chapter, the focus is on the traditional Italian method for making a rollerboard. I will point out the relationship between the final product and the process: such a complex organ part can be made simply, following the ancient way of building, by exclusively using the windchest's ruler and the keyboard's rules. Complex plans and sets of measurements are no longer necessary. For clarity reasons, first, Fig. 5.1 shows the rollerboard in its final form.

Dom Bedos offers a clear view about working principles, as shown in Fig. 5.2.[31]

Figure 5.1



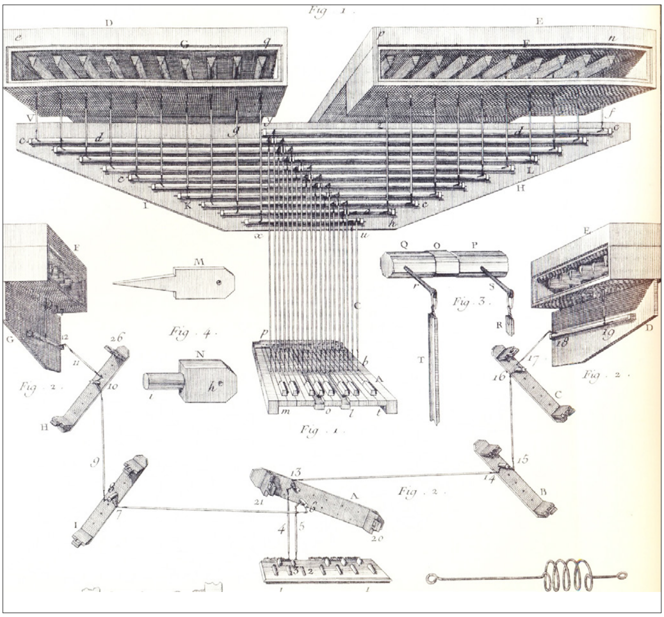


Figure 5.2

31 Bedos de Celles, Dom Francois, *L'art du facteur d'orgues,* Paris: Delatour, 1766–1778.

In almost all early Italian organs, the windchest is a mirror of the facade; more precisely, this means that the sequence of the windchest's channels tends to replicate the order of pipes as they appear on the facade. This choice simplifies the feeding of the facade itself. Consequently, pallets are not chromatically arranged, as the keys are.[32]

The rollerboard can be defined as a mechanical action whose aim is to link the keys and the pallets, both when they do not lie on the same vertical axis, and when the pallets are not chromatically arranged. Thanks to the rollerboards, the key action is spread left and right along the windchest; rollerboards convert the chromatic sequence of the keyboard into an arbitrary order of notes.[33] The nature of an organ keyboard's touch is influenced largely by the quality of the rollerboard. From the Renaissance to the first half of the nineteenth century with the advent of pneumatic action (and later electricity), this was the only manner known in which to transmit the key action to the pallets. This transmission is so effective that, still today, the mechanical organ – a word which extends the mechanical action to the whole organ – is still considered the best in terms of sound control.

5.1. How to make a historical Italian rollerboard (in five steps)

Step 1: The wooden board and initial marks

The first step consists of preparing the board with quarter-sawn fir-wood (a larger size relative to the final measure). Using the windchest ruler, I marked down the position of each pallet along the upper edge of the board; on the opposite edge, I marked the centre of each key using the keyboard ruler.

The distance between the pallet and its key determines the roller's length. The rod had been cut longer to include the two arms. Each rod is then bent to exactly that length: see Fig. 5.3.

Step 2: How many rollers?

The total number of rollers matches the number of pallets which lay off-axis from their keys, as one roller is required for every pallet which is not on the vertical of its own key. In this organ, the total number of rollers is 51.

32 It is quite common to find continental organs which follow the front pipe order. In England the normal arrangement is to have the largest pipes on the outside and the smallest in the middle, in organs of any size. In Spain many historical organs can be thought of as two half-organs jointed together: the right half (up from the middle Do#) follows the chromatic order, while the left half (down from the middle Do) is specularly oriented. The windchest is normally split in two: left and right.

33 I personally appreciate the Latin name *compendium*.

Step 3: Material for rods and processing techniques

Following the Italian tradition, I used iron rods, a metal which is similar to the ancient one. A diameter of 5 mm is typical. Iron can be easily cut at the proper length by a hand-held metal-saw. Similarly, it can be bent into the typical[34] "U" shape using a standard vice and a hammer.

In order to avoid mixing up the rollers – sometimes their lengths are similar – I developed a slotted beam labelled with keynotes. Fig. 5.4 shows all rollers, temporarily hanging on the slotted beam, ready for the next operations.[35]

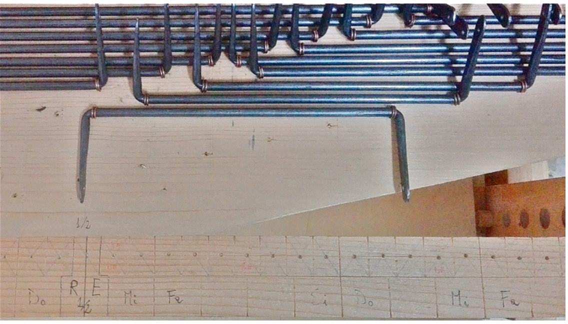


Figure 5.3

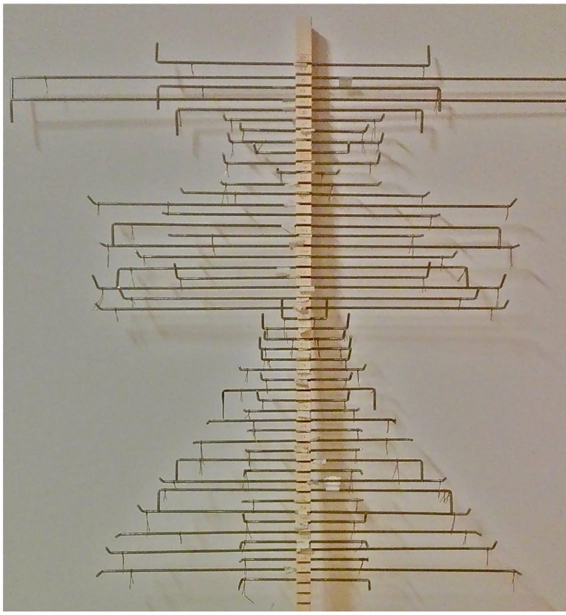


Figure 5.4

34 Rollers made of wood demand more vertical space. Moreover, considering the effect of the climate on wood, metal rollers are less apt to require repeated regulation on the trackers.

35 During my residency at the Deutsches Museum, I was assisted by Michael Zahnweh, a musicologist, to whom I assigned the development of the rollerboard. He managed the task perfectly, without any previous experience, and easily designed the rollerboard by following the above-mentioned steps.

The two arms of each roller must be flattened down to host the hook. Iron can be easily forged when locally heated until it becomes red; at that temperature, it becomes malleable, and so can be flattened down by hammering on an anvil (see Fig. 5.5).

Fig. 5.6 shows a few preliminary tests on material using a blowtorch for practical reasons; subsequently, when I was back in my workshop, I used a wood stove to heat a few rollers at the same time, showing how this historical method is practical and effective.

A small hole is then made to hang the trackers: see Fig. 5.7.

Step 4: How to arrange rollers on the rollerboard

Of all the ways in which rollers can be arranged on the rollerboard, the best combination is that which requires minimal space consumption. To do that, where possible two or more short rollers should be laid down on one single line, saving space. The compactness of the rollerboard limits the distance between keyboard and windchest.

The combination of narrow diameters of rods and coils made of wire maintains the interaxis between rods at around 7 mm,[36] so that the height of the rollerboard is only 230 mm.

Step 5: How rollers are pivoted

Great relevance is given to the pivot,[37] a handmade double coil of good-quality brass. The pivot's role is to keep each roller fixed at its specific position, ensuring that it can turn freely. Some organ builders limit the eyes to a single coil (the one on the left in Fig. 5.8); this is risky because, due to their drop-shape, the lower corner could be easily depressed into the wooden board, so that roller and wood come in contact.

By contrast, I opted for the double coil (the one on the right in the same figure): the wire passing under the roller definitively avoids contact between the roller and the wooden board.

Figure 5.5

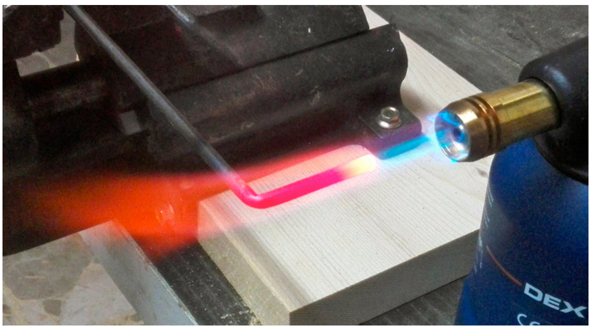


Figure 5.6

36 The interaxis is 11 mm for aluminium rollers; with wooden rods, the interaxis would be 15 mm or more.

37 The Italian name *strangoli* ("strangles") perfectly conveys the concept of its action.

Figure 5.7

Figure 5.8

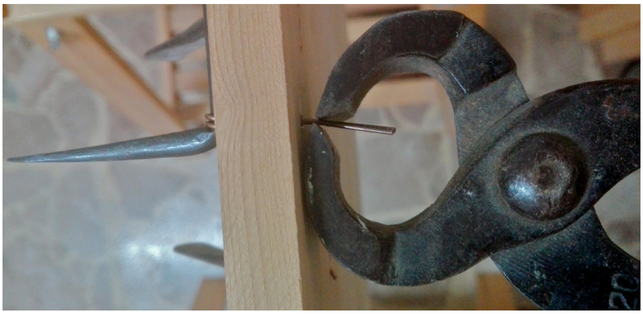


Figure 5.9

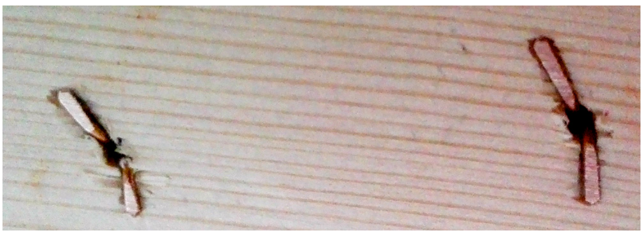


Figure 5.10

The twisted ends of the eyes are first stuck in a pinhole previously marked on the rollerboard (Fig. 5.9 shows how this old pair of pincers is the right tool to pull out an eye's legs); subsequently, from the back side, they are opened and hammered into the wood. Neither screws nor glue are necessary to fix coils into the board (see Fig. 5.10).

The pinholes are directly marked down on the board, placing the rod in its position. To prevent sideways swing, precise marking is required. The tilting angle will ultimately be only a few degrees (less then 5°), but the perfect free rotation must be tested with a larger angle. The test, as always, is given by hand, raising up and then releasing each roller. A good result is reached when the finger experiences the weight of the two rollers' arms only, without any friction.

Fig. 5.11 shows the rollerboard when ready.

We know from historical organs that the durability of such a simple and effective mechanical action lasts largely through the centuries.

5.2. Comments on the noise produced by the rollerboard

The mechanical action described above can be defined as "unbushed", as metal parts (namely the coils and rollers) are in direct contact with each other, without any felt/leather. By pressing the organ keys, especially trilling on two of them, a typical "metallic noise" can be heard. This is due to the impact between the coils and the rollers. This noise is lower when the coils fit the rod diameter perfectly, a condition which simply corresponds to good skill in rolling up coils by hands. This typical metallic noise was so common in early organs that we have to consider it part of the aesthetic of the sound.

The evolution of rollerboards with respect to Renaissance style concerns many details relating to the technology of the time. See Appendix A3 to compare this building method with others.

Figure 5.11

6. Pipes and their construction

Introduction

The organ of the Silberne Kapelle offers to modern organ builders the unique opportunity to acquire original pipe measurements from a sixteenth-century Italian *organo di legno*.[38]

The aim of this chapter is to introduce the reader to the right approach to the original measurement of pipes: since the organ was manipulated a lot in past centuries, a few interpolations and precautions are necessary before using the pipe's measurements.

A pipe's dimensions, such as the length of the body, wall thickness, mouth cut-up and toe holes, are essential and unescapable parameters which describe the unique work that has survived until today. They can be considered the signature of the builder, the most important evidence and proof of the research behind that organ.

Unfortunately, the organ in question has been manipulated a lot in the past, and by more than one hand. As described by Donati in his paper[39], ranks of pipes were mixed up (see Introduction) and consequently pipes were adapted to fit the "new" collocation and blend with the others. How heavily those modifications affected the pipes can be understood by looking at the organ after the last restoration, which occurred in 1996, whose aim was to move the pipes back to their original position and extend the pipes' bodies to the original length.

Therefore, the current pipe measurements would be not the best choice for me to use: preliminary realignment and adaptation of the measurements were necessary before building pipes.

6.1. The measurements of the pipes

A deep analysis of all parameters and their reshaping is not within the scope of this publication, I therefore report here only the main results I got.

Starting from the measurements available in the paper by Donati, I plotted the main parameters (internal width, mouth heigh) for the main stops (Principale, Ottava, Flauto in XII). Subsequently, I marked a "guide line" to provide a visual interpolation.[40]

38 Reiner Janke, "The secret of scaling", *ISO Journal* 49 (2015): 50–64.

39 Donati, *L'organo*, 2006, here specifically see Fig. 8.

40 On explaining how to plot and scale pipe parameters see Andreas Ostheimer, "The scaling triangle in pre-industrial organ building", *ISO Journal* 42 (2012): 8–22; Wolfgang Eisenbarth, "The basic principles of scaling and voicing flue pipes", *ISO Journal* 51 (2015): 7–48; Mad Kjersgaard, "Fingerprints of Ancients Masters", *ISO Journal* 54 (2016): 8–29, and *ISO Journal* 55 (2017): 58–77.

The mouth cut-up, whose progression is quite regular, is the most important parameter: it has a direct effect on the spectrum of sound, and is much more relevant than the pipe's size. Nevertheless, interpolation was useful to produce a more regular progression of pipe size.

I also optimised the progression of the thickness of walls: the original progression of thickness was not regular enough to be taken as a definitive measure. More precisely, there are pipes in which the thickness of walls is quite different side by side: there are big pipes with extremely thin walls (among pipes with more reasonable ones), and so on. Experience shows how to make these values more regular and consistent with the function of the walls.

Here are my plots:

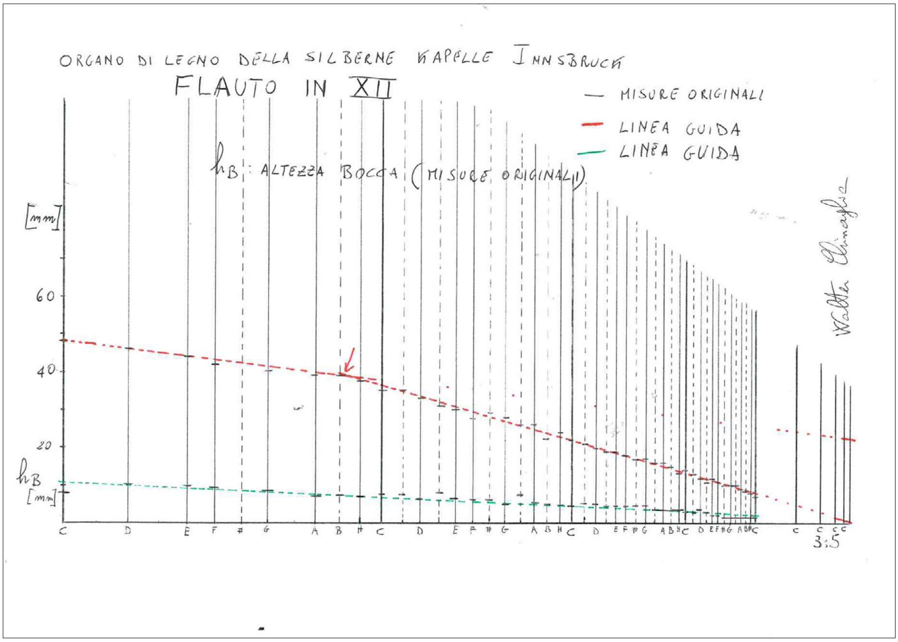


Figure 6.1a

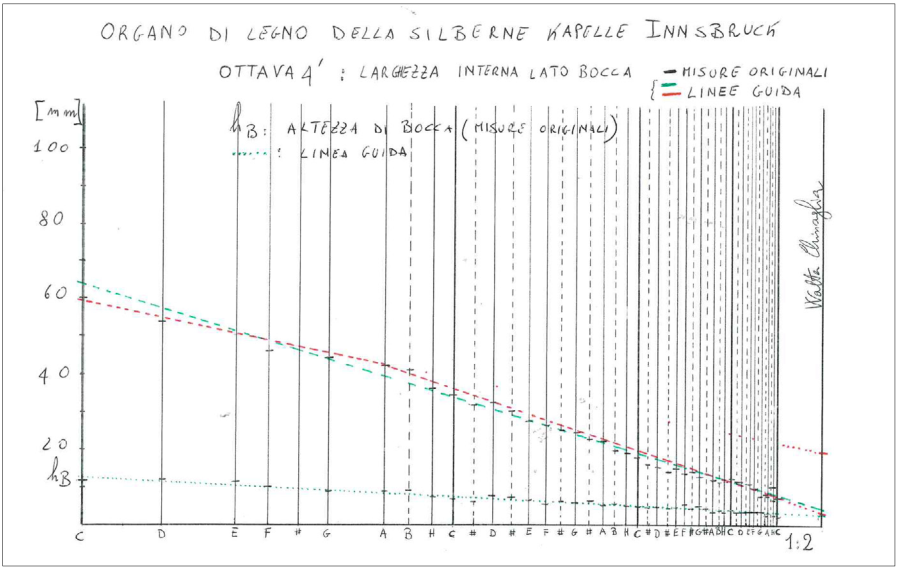


Figure 6.1b

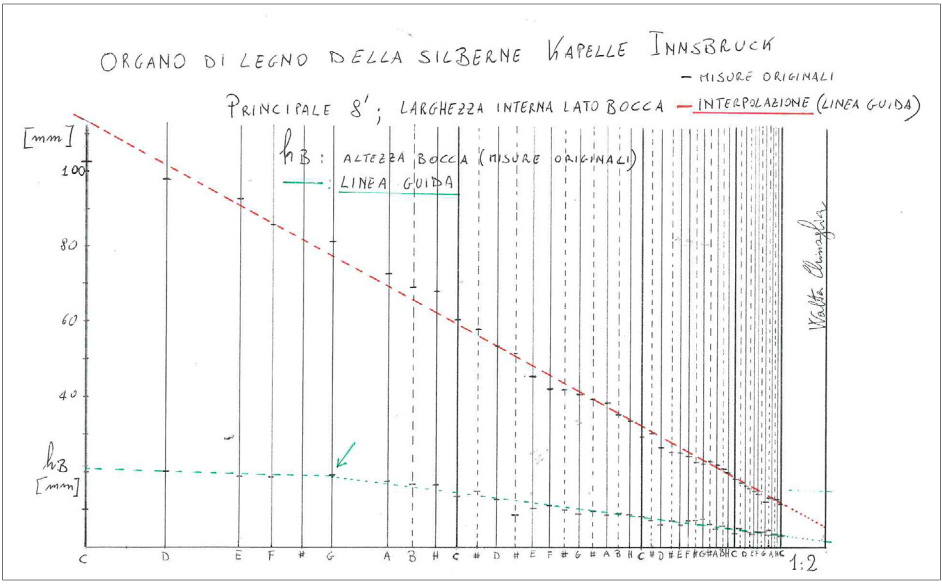


Figure 6.1c

6.2. How to glue small wooden pipes

Fig. 6.2 shows a simple but effective way to clamp small pipes using a waxed wire.

Waxed wire offers a few advantages:

- It can be wrapped around the pipe quickly (this is relevant when hide glue is used, because it gels in only a few seconds);
- thanks to the wax, when tightly wrapped, it does not tend to unroll;
- it is waterproof, so it does not absorb the glue;
- it can be quickly unrolled;
- it can be reused.

6.3. How to glue large wooden pipes

To glue large pipes, I developed the clamps shown in Fig. 6.3. They were developed to set quickly, to keep pressed pieces in position (with no sliding), and to give longitudinal pressure.

Since hide glue has quite a short open time, for medium-length pipes (4 ft) I glued the back side first (see Fig. 6.4) and subsequently the front side (see Fig. 6.5).

The longest pipes were glued in four stages: half the length of each side first, then the second half. This was possible thanks to the flexibility of the wood, which can be gently lifted up to apply glue.[41]

Thanks to the rigidity of well dried hide glue, which gives excellent sound transmission between parts, a one-body resonance is reached: this can be experienced by knocking on large pipes.

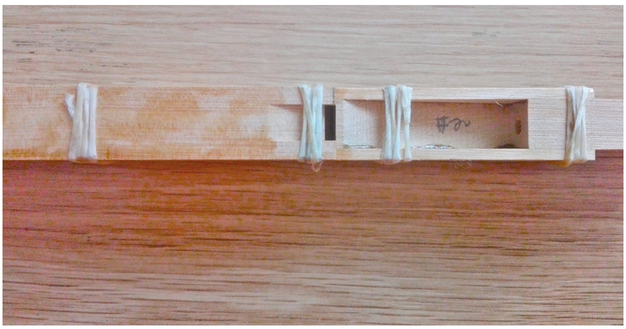


Figure 6.2

41 Alternatively, the longest pipes can be glued in one shot by using modern aliphatic or vinyl glues, which offer a quite long opening time.

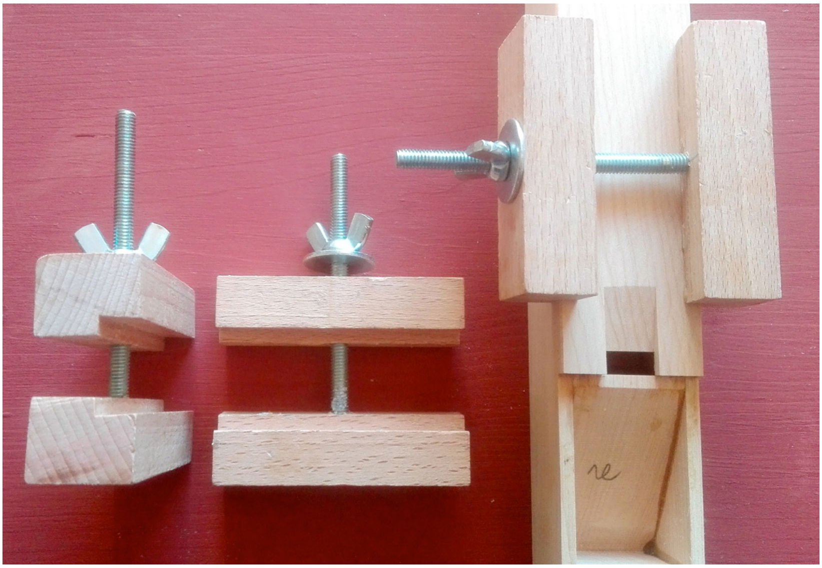


Figure 6.3

Figure 6.4

Figure 6.5

6.4. How to build the pipe feet

In this paragraph I will show the method I used to replicate the pipes' feet. Although a modern alternative would also be possible, the ancient method can be considered preferable for this organ.

In the Silberne Kapelle's organ, the pipes' feet are carved out directly from each pipe's block, as shown in Fig. 6.6; they are pyramidal with a central hole as a wind-way. This is the case from bass to treble, from the largest wooden pipes to the smallest.

Contrastingly, an example of modern pipe foot is shown in Fig. 6.7.

These are generally shaped using a lathe, and they are turned as a separate part of the pipe. They are plugged into the pipe's block where a hole has been prepared. Thanks to modern technology, a wide range of pipe feet is available on the market. They are often equipped with a regulating screw/flap, as Fig. 6.7 shows.

For my organ, I decided on the former option: not only to satisfy the eyes, but, mainly, to understand why the pyramidal shape was and is the most reasonable, in perfect coherence with the ancient tools and working actions of the initial pipes' block.

It would have felt artificial to turn about 400 feet, separate from the pipes, precisely scaled to match the progressively small pipes. In early organs, turned feet – like the ones shown in Fig. 6.8 – were used only where aesthetic reasons were predominant, for example in facades[42] or where all pipes were shaped like Italian recorders.[43]

The starting point is a pipe, almost complete of its single parts, like the two in Fig. 6.9. As we can see, the block exceeds the pipe's wall and the hole along the block's axis is done before gluing the pipe.

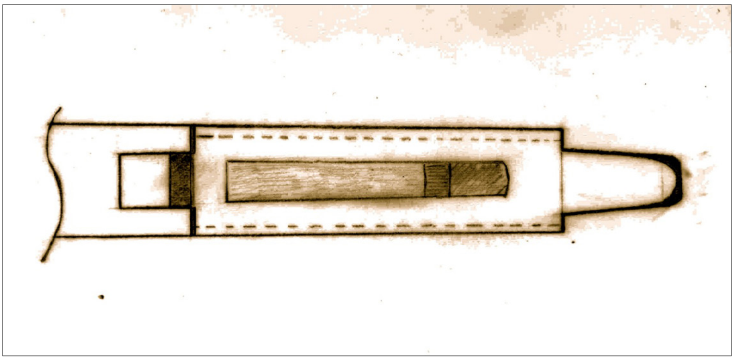


Figure 6.6

42 Friedrich Jakob, *Die Orgel und das Holz,* Männedorf: Verlag Orgelbau Kuhn, 1997.

43 Enrico Peverada, "Un organo per Lionello D'Este", *L'Organo* 28 (1993–94): 3–30.

Figure 6.7

Figure 6.8

Figure 6.9

6.5. How to trace a pyramidal shape from a squared block

I started from the bottom, where the hole is visible. The presence of mechanical tolerances in the drilling action allowed for the production of holes slightly off from the centre of the block. (I used a hand drill, which reproduces the level of accuracy which is believed to have been possible in the sixteenth century). Since the hole and the pipe toe have to coincide at the end, I developed an effective jig to set the pyramidal foot exactly where the hole is.

The jig and a razor saw used to mark down lines are shown in Fig. 6.10. They can be used to mark four perpendicular lines perfectly centred around the foot hole, "indulging" the jittering of the hole (see Fig. 6.11).

Using a hand saw and paying attention to the angle of the blade, I cut the four sides of the foot starting from the marked lines as far as the pipe's wall, as in Fig. 6.12. The pyramidal foot emerges after cutting away the lateral pieces of wood, as in Fig. 6.13.

As the pictures show, cutting by hand is possible: it requires a good deal of time and concentration, but it is doable. As an alternative to hand cutting, I used an electric bandsaw, equipped with another jig which runs straight on the bandsaw plane together with the pipe; the aim of the jig is to maintain a fixed angle with respect to the blade. The result is visible in Figs. 6.14 and 6.15. The angle between the blade and the sliding direction can be easily adjusted to fit all foot sizes.

Figure 6.10

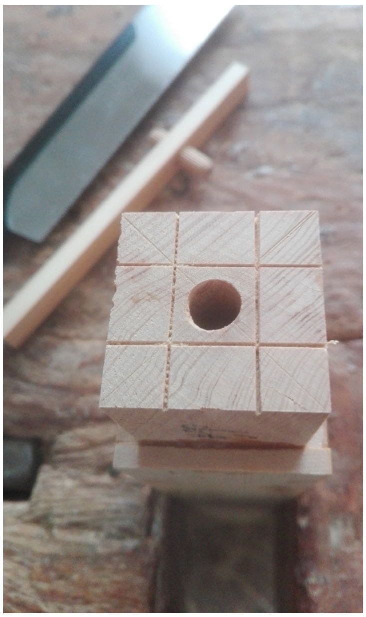


Figure 6.11

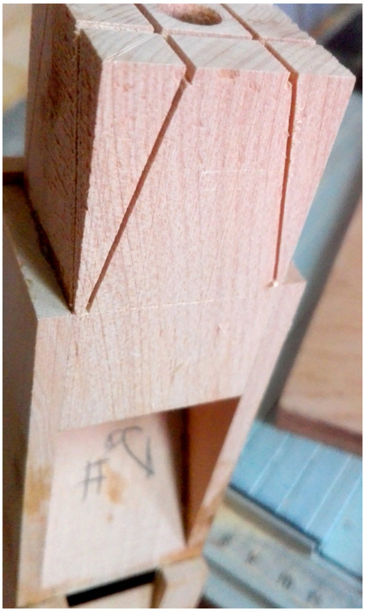


Figure 6.12

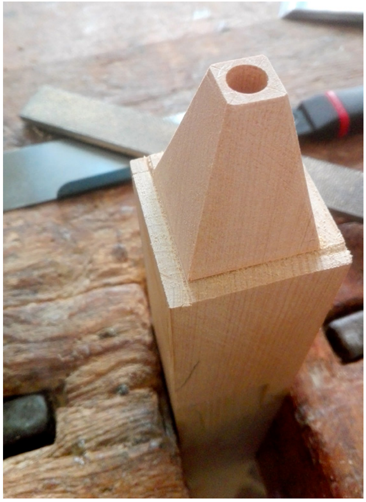


Figure 6.13

Figure 6.14

Figure 6.15

The last step is to make the toe perfectly round, in order to guarantee a good airtight when the pipe is planted on the windchest. For smaller pipes (from Do4 upwards) I used the so-called coning-in tool (see Fig. 6.16), a metal cone typically used to reduce the size of toe holes in metal pipes. As wood is not as malleable as metal, a flame was necessary to heat the cone (see Fig. 6.17). When it became burning hot, the toe was easily and uniformly rounded with light pressure. Local burning is visible. The results are shown in Fig. 6.18.

For larger pipes, this method would be much too aggressive, as the burned area increases according to the size of pipe. In those cases, I mostly used a good rasp and subsequently a file, having found no other specific tools in literature. The critical point is the angle of the rasp with respect to the axis of the foot, which has to guarantee a uniformly rounded toe. I developed a simple jig, shown in Fig. 6.19, for training the hand into maintaining the same angle sliding the rasp all around the foot.

With a certain amount of practice, a good result can be achieved.

A somewhat more modern approach consists of a toe cone coated inside with sanded paper; by rotating the toe cone, the abrasion on the toe is uniform and regular. The sandpaper must be frequently renewed. This tool is also excellent for finishing toes. Perfect air-tightness on the windchest can be easily achieved, as shown in Fig. 6.20.

6.6. Comments

Turned pipe feet are not a natural solution for the context and tools of the era in question. Pipe feet were cut directly from the block, after gluing the pipes. A hand cut is possible, or alternatively a bandsaw can be used. The toe is rounded using coning-in tools. Precise results are guaranteed by this process, since it takes into account the capacity and imperfections of real manual work. A modern procedure, aiming for perfect symmetry around the centre, would not produce the same good results.

Figure 6.16

Figure 6.17

Figure 6.18

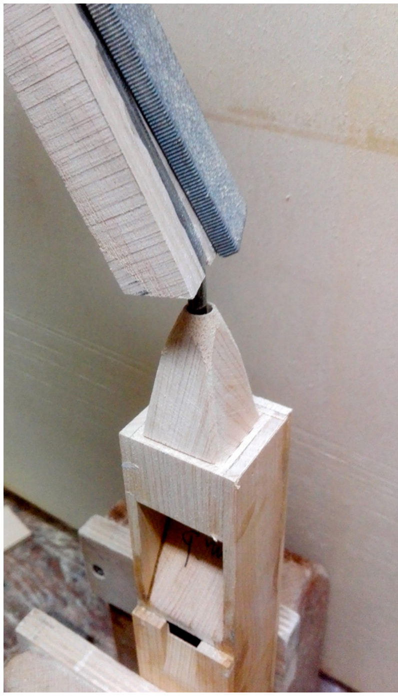


Figure 6.19

Figure 6.20

7. The spectral analysis of the sound

Introduction

As soon as a few pipes were ready, they underwent a preliminary measurement of their sound spectrum: the two families of stops, "Principali" and "Flauti", were analysed by means of a spectrometer. The aim was essentially to show the correlation between the pipe's parameters (such as diameter, mouth width and cut-up) and the produced sound.

Of course, an extensive analysis requires more time, as well as a complete measurement set-up, in order to record the pressure, the wind amount, the initial transient of sound, the emitted power, and so on. Nevertheless, with the basic instrumentation available, I obtained interesting results.

7.1. Wooden Principale and wooden Flauto

Fig. 7.1 shows the spectrum of a wooden pipe belonging to the Principale (the column on the left) and the same note from a Flauto pipe (on the right). Each horizontal line corresponds to one harmonic and the bottom line is the fundamental frequency. The brightness of the line shows the intensity (in arbitrary units).

In brief, we clearly see how the Principale pipe shows a whole spectrum in which all harmonics are present, both even and odd. The Flauto pipe shows a relative cut-off in high frequency harmonics, mainly due to the high mouth cut-up, as organ builders know quite well.

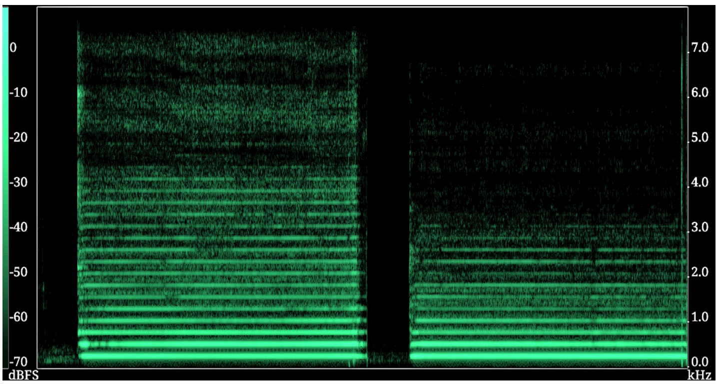


Figure 7.1

Figs. 7.2 and 7.3 show another way to plot the spectrum: each peak corresponds to one harmonic, and the intensity of it is given by the peak height. These two pictures show the spectrums of a Principale pipe and a Flauto respectively, as already shown in Fig. 7.1.

By looking at these pictures, we can see the effect of the size of the pipe (resonator): thanks to the large scale, the fundamental partial of a Flauto pipe is more intense than the fundamental of a Principale pipe. This describes the two families of stops (namely Principali and Flauti) which are at the basis of early Italian organs.

It is not difficult – even without measuring more accurately – to understand why the mouth width of the Flauto pipe is narrower than that of the Principale: this choice by the original builder balances the emitted power, so that the two families, Principale and Flauto, can be easily blended.

7.2. The role of the wall material: Principale from metal and from wood

Fig. 7.4 has been taken from measurements done for my project *Duoi organi per Monteverdi.*[44] It shows the spectrum of a historic Principale pipe in metal (left), the equivalent in wood (centre) and the same tone produced by a stopped wooden pipe (right).

This picture shows how the spectrums of Principale in metal and in wood are very similar: the role of the material is not so relevant for the timbre.

7.3. The spectrum of a stopped pipe

Finally, considering the right-hand column of Fig. 7.4, which shows the stopped wooden pipe, we see the absence of the even harmonics in the spectrum, accompanied by the high frequencies cut-off.

Although this combination produces a vaguely flute-like timbre, stopped pipes were never really appreciated in early Italy.

44 See Chinaglia, "Duoi organi", https://www.organa.it/monteverdi, accessed 17 December 2019.

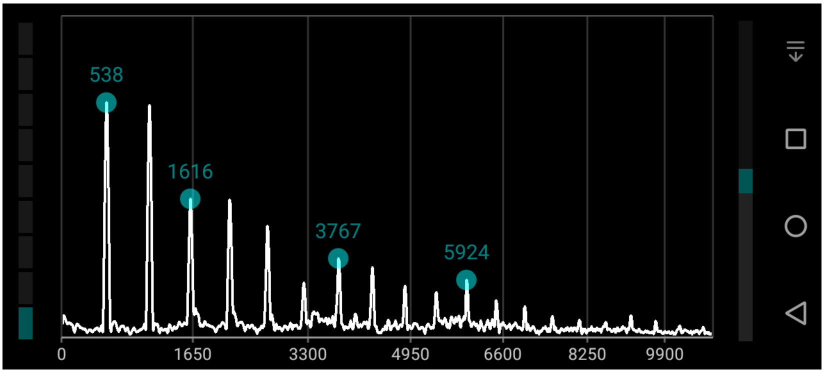


Figure 7.2

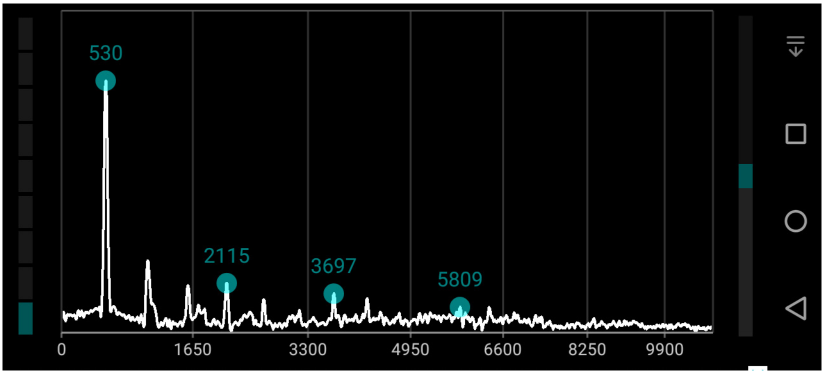


Figure 7.3

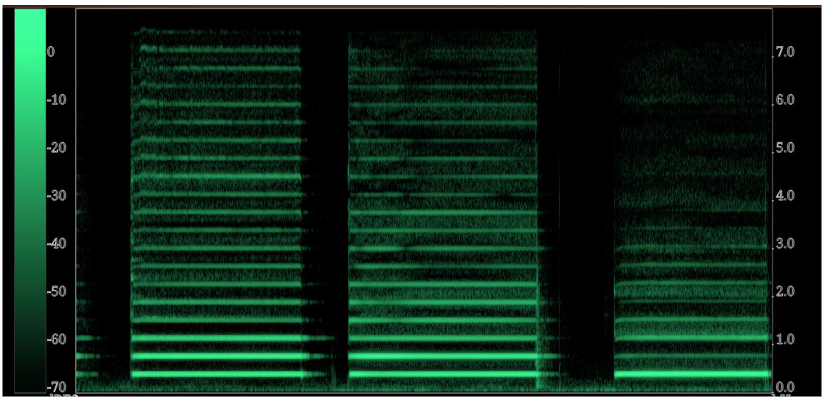


Figure 7.4

Appendix

A1. How to cut a log

There are three typical ways in which a log of solid wood can be cut. For each one, I will briefly show the advantages and disadvantages. I will also show how the keyboard and the windchest require two different cuts with opposing properties.

Organ builders, like other instrument makers, pay high attention to the quality of wood they use. Top-quality solid wood, well seasoned, stowed for years under good conditions, is just the starting point from which to achieve a perfect result in organ building. Several parts of the organ must be dimensionally stable (for example, the keys, the windchest's soundboard, the pipes); this stability leads to a well regulated and stable mechanical action, and good air-tightness in the windchest, which is responsible for tuning stability. The perfect result is achieved by a combination of two factors: the correct building technique (how each part is conceived) and the specific way in which timber is cut from a log.

Method 1: plain-sawn (flat-sawn)

Plain-sawn or flat-sawn is the most common type of cut, and the cheapest; this is therefore the cut used for common timber on the market. It is shown in Fig. A1.1. The angle between the face of the board and the annular rings is 30 degrees or less.

The resulting wood displays a flame-like pattern on the face of the board because the cut is tangential.

Figure A1.1

Method 2: quarter-sawn

Only a few sawmills offer quarter-sawn wood because each log is initially sawn into four quarters (hence the name) at a radial angle, and then each quarter is sawn into bars, as shown in Fig. A1.2. The angle between the face of the board and the annular rings is 60 degrees or more, up to 90 degrees.

The resulting wood displays a perfectly straight grain pattern.

Method 3: rift-sawn

Rift-sawn wood is the least common and the most expensive, since it produces the most waste (large triangles). The boards display a straight grain pattern on their faces, and can therefore be assimilated into a quarter-sawn cut, especially because it is also referred to as a radial grain.

In conclusion, quarter-sawn and rift-sawn are the best choices for making pipes and windchests, because the planks maintain perfect planarity. By contrast, the best stability for the keyboard is achieved by using plain-sawn wood: here the straightness of each key is fundamental, and planarity can be optimised by regulating the keys' height.

A2. The transient control

Transient control is the ability to influence the sound attack (initial transient) of an organ pipe by means of the key action. It is widely considered fundamental to the proper playing of mechanical organs. In particular, early sources speak of *bona pronunzia* and *spicco*, which are expressions related to the initial transient of the sound. Elasticity of the key action may be responsible for reduced control of the sound attack, if the pallet does not suddenly and exactly follow the key movement.[45] Iron rods show the smallest torsion coefficient (torsion is the reaction to the two opposing forces applied, namely the key action on one side, and spring and air pressure on the other); so that they perfectly replicate the tilting angle from one edge to the other (along the axis).

When modern rollers (like the ones described in Appendix A3) are made of aluminium instead of iron, the diameter of the rods must be augmented from 5 to 10 mm to give a similar torsion coefficient. Consequently, the rollerboard is larger and less appropriate for early Italian organs.

45 See Alan Woolley and Donald M. Campbell, "A musical and mechanical study of tracker actions", *ISO Journal* 56 (2017): 7–40.

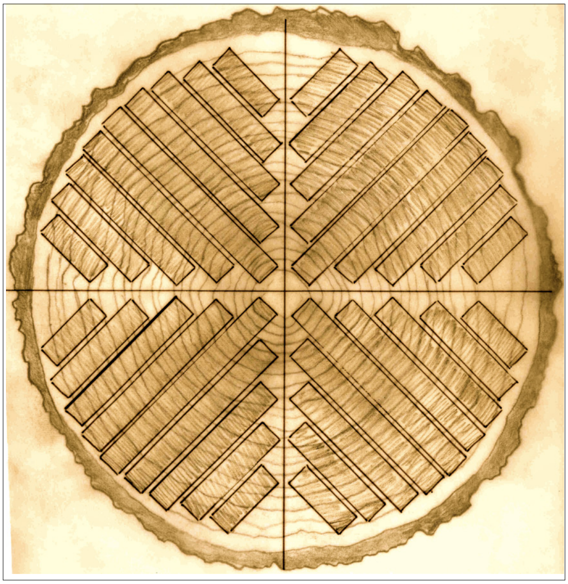


Figure A1.2

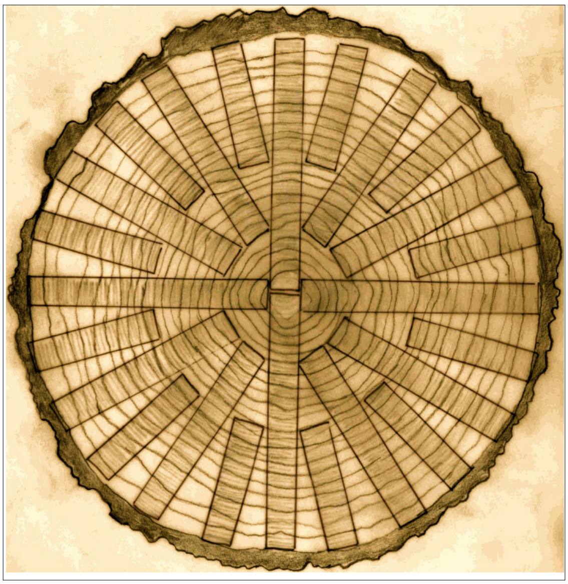


Figure A1.3

A3. On the modern rollerboard

Are there advantages in making the same rollerboard as described in Chapter 5, but using modern parts and a modern approach? Would the rollerboard be more elegant?

A more modern way to make a rollerboard is based on spare parts available on the market,[46] such as aluminium tubes, threaded arms, tips, plastic nuts, and so on (see Fig. A3.1).

I have used this modern approach several times for new organs, where perfectly silenced mechanisms were required by the customer, for example for practice organs. In that case, I did not apply the method shown in Chapter 5, but instead chose a modern solution as described below.

Let us suppose that we wanted to make a copy of the rollerboard shown in Fig. 5.1, using spare parts available on the market. The historical rollerboard shows the arrival point, but not the process used.

Looking at the picture of the rollerboard, the reader may ask himself how to describe this complex structure in order to replicate it. Probably, the best way is to measure the length of every roller (given in mm), its position on the board, the board dimensions and collect all numbers in a table, as follows:

KEY	first octave	second octave	third octave	fourth octave	fifth octave
Do	518	295	785	223	254
Do#	-	115	86	485	
Re	1104	304	166	226	
Re#	-	468	154	550	
Mi♭	-	805	175	578	
Mi	540	520	170	231	
Fa	1085	755	242	639	
Fa#	475	480	174	238	
Sol	302	790	300	698	
Sol#	-	810	175	244	
La♭	-	678	220	-	
La	240	490	362	735	
Si♭	292	780	219	248	
Si	180	680	422	820	

46 A company which provides such organ parts is Aug. Laukhuff GmbH & Co. KG, Weikersheim, https://www.laukhuff.de, accessed 31 August 2019.

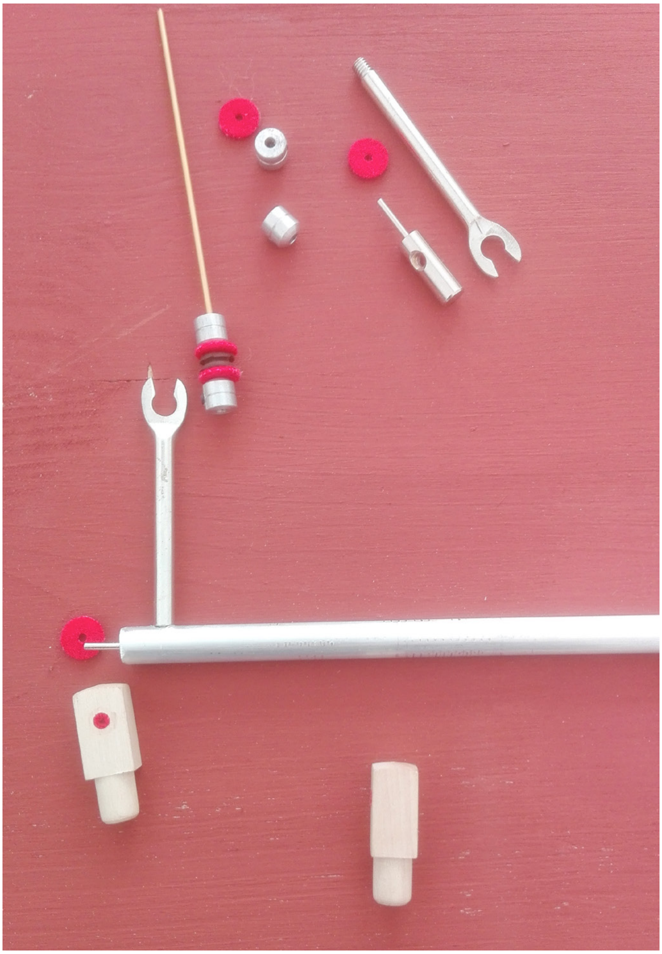


Figure A3.1

To be practical, this table must be linked to a 1:1 scale plan showing the position of each roller on the board.

This set of numbers is simply a list of pieces, totally separate from reality: it does not provide any visual idea to the builder about what he should be doing at every step. With the above table at his disposal, a specialised artisan can cut aluminium tubes to length, then drill the two holes for the arms,[47] fit the tip into each aluminium tube, and finally screw on the arms. Based on the plan, he marks down on the rollerboard the position for the lateral pivots, then drills the rollerboard and inserts them.

The final result is close to the one shown in Fig. A3.2: the tracker action is hung to the roller's arm using small aluminium nuts with a fine screw. Washers of red felt are also inserted to absorb the noise of the single parts.

In conclusion, even though this method offers the advantage of a noise-free rollerboard, it implies much technology, at least to produce all spare parts, which makes it quite expensive.

The operator is not aware of the meaning of the parts and their function within the organ: he is merely an assembler, following a blind table.

Clearly, this kind of technology was not available in earlier times, but also the whole approach was not possible: tables of length measurements only make sense if all builders use the same units, which was not the case at that time. Also, a 1:1 scale plan requires large sheets of paper, which are readily available today, but were not in the past.

For these reasons, I decided to build an ancient-style rollerboard, more coherent with my version of the sixteenth-century organ.

A4. Proportions in organ building

Proportions and bellows

The lower case of the organ houses bellows. The most suitable ones have shorter and longer sides proportioned in a 1:2 ratio: 600 mm and 1200 mm respectively. The proportion 1:2, although not an absolute rule, is quite common in historical bellows.

Proportions and keyboard

Fig. A4.1 shows a keyboard portion corresponding to an octave. It is divided into keys through the use of proportions. Each key corner comes out naturally, according to the intersection of lines.

When a wooden plank is cut to make a keyboard, the procedure does not change. The interspace between keys is determined by the thickness of the saw blade.

47 The parallelism between the two arms is achieved by a special jig made of stainless steel, provided by Laukhuff, see footnote 46.

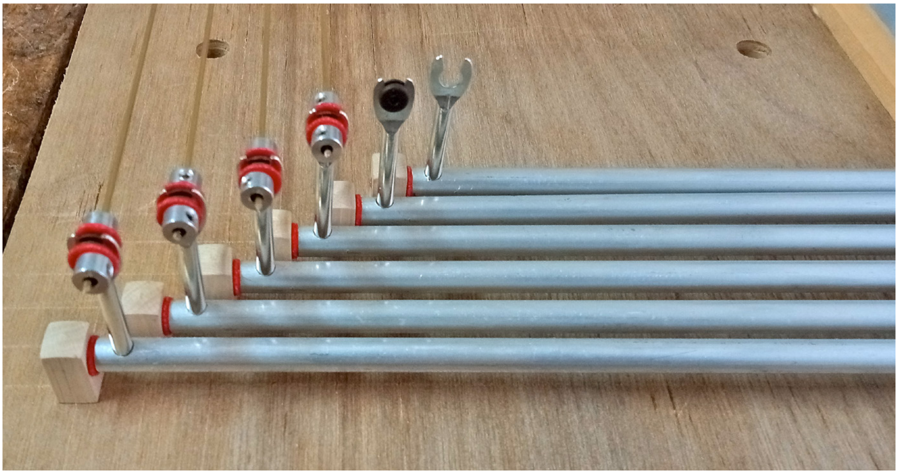


Figure A3.2

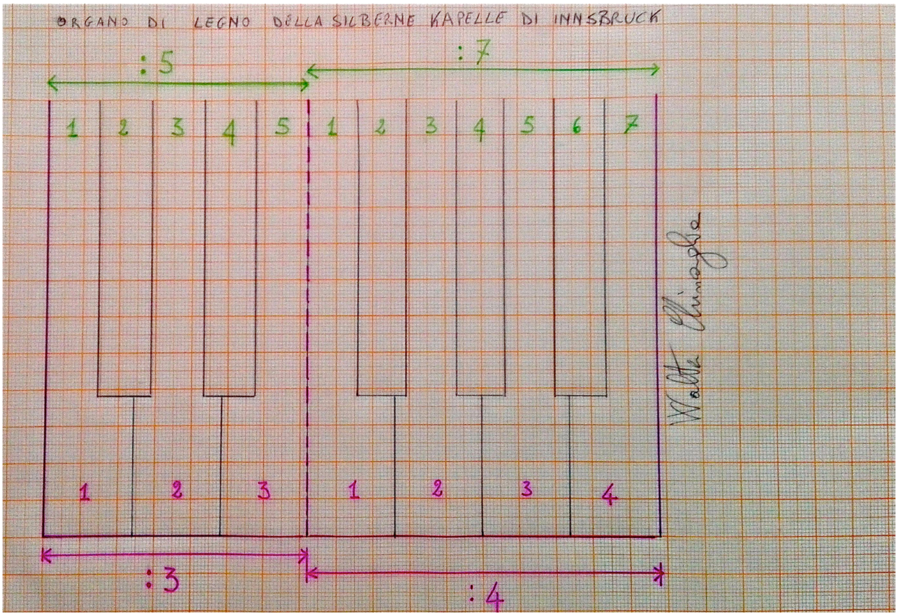


Figure A4.1

Proportions in pipes' mouths

It would require more space to compare the mouths of pipes from the Silberne Kapelle organ with those of other organs. Here, I simply report the main proportions I used in making pipes accordingly with original organ as described by Donati.[48]

Fig. A4.2 shows mouth (labium) proportions for Principale stops (and all other stops of the family), on the left, and for Flauto, on the right. The former mouth corresponds to one half of the total width, while the second corresponds to a third.

Proportions and temperament

Proportions are not only involved in the division of keys, but also in musical intervals. The ratio 1:5 defines pure major thirds[49] ("pure" meaning without audible beats), and it is the basis of so-called meantone temperament.

The most proper temperament for a sixteenth-century organ is a regular temperament called quarter-comma meantone, in which all fifths but one are tempered by the same amount.[50] Thanks to this choice, eight major and minor keys sound especially good. Meantone temperament is linked to the adjective "chromatic" since passages over semitones sound especially effective because of their two different half-steps.

The circle of fifths is not closed, because the interval between Sol# and Mi♭ is closer to a dissonant diminished sixth than to a fifth; consequently, this interval is called the "wolf".

The name meantone derives from the central position of Re in the major third Do–Mi.

Split keys make the major and minor semitones[51] within a whole tone usable. Of all the tones, the most useful for the repertory are Re–Mi and Sol–La, which are respectively split into Re# and Mi♭, and Sol# and La♭.

A5. A different windchest based on the Antegnati method

The aim of this appendix is not to analyze other historical ways to make a windchest in detail, but rather to demonstrate how building layouts were developed to deal with specific limitations which resulted from particular materials and situations. In order to do this, I will briefly explain the Antegnati method for building windchests.

48 See Donati, *L'organo*, 2006: 67.

49 More precisely, 5:4 is the ratio between Do and Mi within the same octave.

50 See, for example, Ross W. Duffin, *How Equal Temperament Ruined Harmony (and Why You Should Care)*, New York: W.W. Norton & Company, 2007.

51 Ibid.: 52.

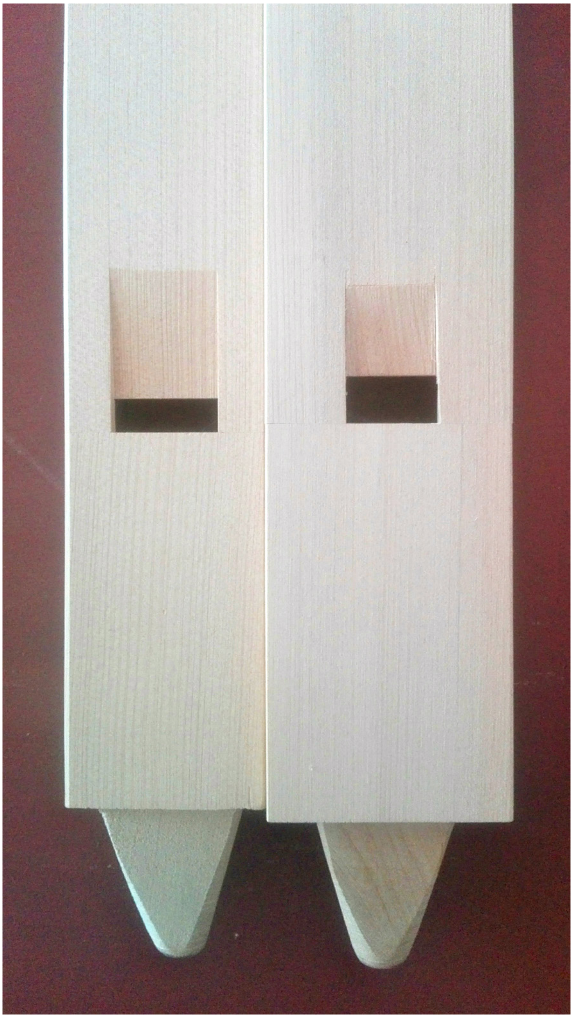


Figure A4.2

As shown earlier, my windchest is structured as a grid. It consists of a frame and bars of quarter-sawn larch: this layout offers a high level of mechanical stability and it ensures the flatness of both surfaces. Flatness of the soundboard plays a fundamental role in maintaining the perfect tuning of the organ and acts against extraneous sounds.

In contrast, a copy of the original windchest of the Silberne Kapelle organ would be affected negatively by modern heating systems and room conditions. In fact, as seen before, there is evidence that solid boards (of walnut) are subject to torsions. If, in unheated churches or palaces, such kinds of windchest could survive for decades, in modern rooms it should be advised against. Another good layout for medium-sized early organ windchests is the one largely used and recommended by Antegnati.[52] In giving this example, I underline the relevance of the interconnection between building technique and materials. In fact, for quite big windchests and metal pipes, ancient organ builders developed an elegant alternative to the traditional soundboard.

A reproduction of the sketches from Moretti's book[53] is given in Fig. A5.1 in order to explain the general principle.

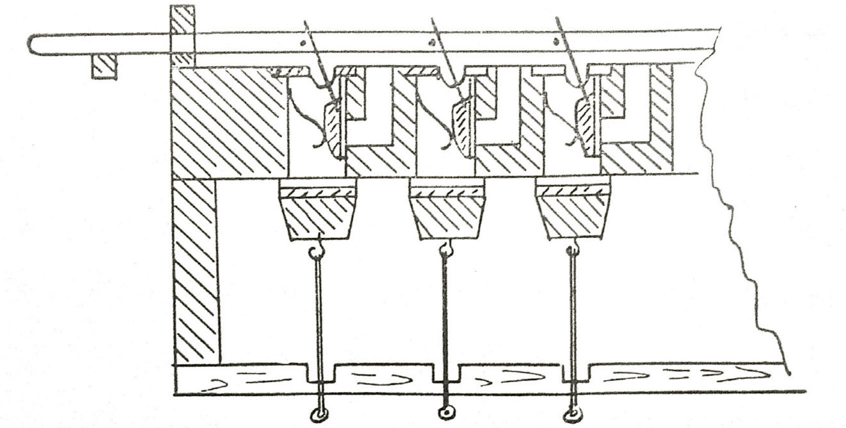
By comparing this layout with the windchest described in Chapter 2, we can immediately see a major additional complexity here: instead of one slide for each stop, we find here one small pallet for each pipe, located in the corresponding groove. Three small pallets are shown in the top sketch in their closed position, while the open position is shown in the lower sketch. The mechanism which controls their simultaneous movement is a sort of comb, a strip of wood with pins.

This quite complex layout offers the following advantages:
- No slides slip between two flat surfaces (there are no air losses which generate extraneous sounds and mistuning);
- Perfect flatness becomes less important: it is relevant only in the small area where pallets have to provide perfect airtight;
- The weight of each pipe – quite significant in the case of metal pipes – is concentrated on the bars, rather than on a thin sheet of walnut;
- The mechanical action for stops is placed on the top of the windchest, between the pipes, so it shifts freely.

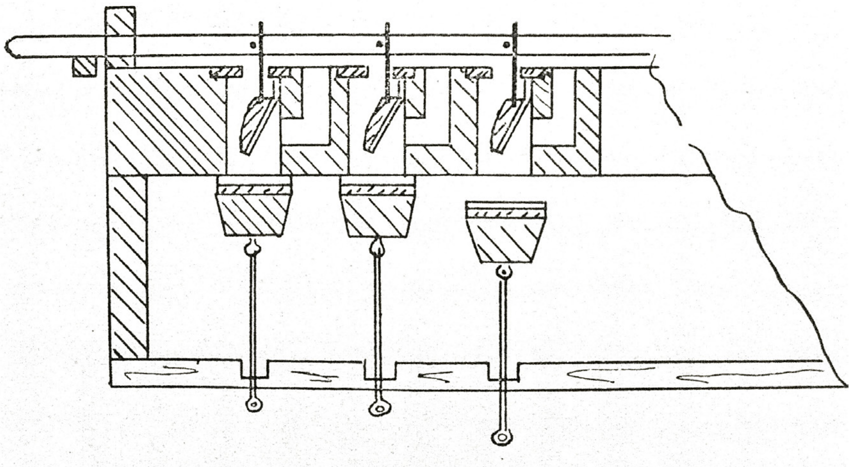
As usual, a few downsides come along with to the advantages listed above, but I will not discuss them here, since this kind of windchest is not the one we found in the organ of the Silberne Kapelle.

52 An organ after Antegnati was made by Daniele Giani in 2015: see Giani, "Provaglio d'Iseo", http://organibresciani.org/organo.php?ID=401, accessed 31 August 2019.

53 Corrado Moretti, *L'organo italiano. Profilo storico, analisi tecnica ed estetica dello strumento, sintesi delle sue sonorità a servizio della liturgia cattolica,* Cuneo: S.A.S.T.E., 1955: 83.



Somiere a vento, chiuso.



Somiere a vento, aperto.

Figure A5.1

A6. On hide glue and its advantageous use

This appendix is devoted to showing the advantages of the use of hot hide glue,[54] instead of normal vinyl or aliphatic glues, when the aim is to re-create the historic manner of working. Fig. A6.1 shows one plate of hide glue[55] in a bowl of water at room temperature.

It is similar to a glass plate: extremely rigid and fragile. It can only be broken using a hammer. I found a few hundred plates when visiting an old cabinet maker's workshop: they were rendered defunct in the 1950s with the advent of modern glues, which definitively replaced hot hide glue.

After a few hours in a bowl with water at room temperature (allowing the water to be absorbed), the glue is ready to be warmed up. I used an electric glue pot made of aluminium to heat the hide glue inside a water bath. The temperature should not exceed 70°.

Once the glue has been heated sufficiently, it becomes liquid enough to be used. By raising the brush 40 cm above the top of the pot, a typical noise is produced. Old cabinetmakers told me: when the glue starts "singing," it holds the right amount of water.

Figure A6.1

54 A short article on hot hide glue is Vincent Mrykalo, "Hot Hide Glue", at: http://www.academia.edu/4210006/HOT_HIDE_GLUE, accessed 31 August 2019.

55 Today, it is available on the market in granulated form.

The advantages of using hot hide glue can be summed up as follows:

- The initial tack action greatly helps the user to set strips of leather/cloth; it is especially useful to set gusset, butterflies and corners, since leather can be tensioned (extended);
- Once dry, it is perfectly rigid (like glass) so that it breaks along the fold (hinges) after the first bending and subsequently any rigidity or elasticity disappears (in contrast, vinyl glue cannot be broken because it acts like a gum);
- It is reversible – its most important property – so that it can be easily removed by hot water/steam at any moment, for instance during restoration;
- Regarding the transmission of sound, it offers the best coupling between soundboards: it should be used in all stringed musical instruments in which soundboards are responsible for the energy transfer to air.

To my knowledge, there are no scientific studies which investigate whether the sound of wooden pipes benefits from the use of rigid glues. So I cannot prove the positive impression I have, which is that the rigid glue is the best choice for open wooden pipes, especially when the full spectrum of sound is the final goal.

While I am sure that such thin glue film does not have a direct effect on the sound (it does not add harmonics), I nonetheless appreciate the "one-body" resonance perceptible by knocking at the pipe's walls, which surely contributes to well developed stationary waves inside the resonator.

Surely, rigid glue plays a relevant role in the famous organ with paper pipes, dated 1494, by Lorenzo Gusnasco "da Pavia," of the Correr Museum in Venice.[56] I believe that the kind of glue influenced both the rolling-up techniques and the sound.

Modern aliphatic glue[57] imitates hide glue's rigidity quite well. This glue can be used at room temperature, directly from the bottle. This is the most reasonable alternative to hide glue, but unfortunately it is not reversible, and there is no scientific literature about the durability of such polymers over centuries.

56 Emanuele Marconi and Jean-Philippe Echard, "The Organ with Paper Pipes of the Correr Museum in Venice. A Review and New Insights", *Journal of the American Musical Instrument Society* 39 (2013): 89–142.

57 The most used is Titebond, http://www.titebond.com, accessed 31 August 2019.

A7. Photographs

Fig. A7.1 My temporary workshop at the Deutsches Museum

Fig. A7.2 Gluing wooden pipes

Fig. A7.3 Testing the fluidity of hide glue

Fig. A7.4 Gluing butterflies and gussets on the bellows' corners

Fig. A7.5 The upper and lower leaves, hinged by a strip of strong cloth; it is a good rule to bind parts using a rope.

Fig. A7.6 The set of early tools

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List of Figures

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