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11. MUSIC AND ENGINEERING - A NEW PARADIGM OF ARTS AND ENGINEERING EDUCATION

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Abstract: *The paper presents the interdisciplinary approach of two fields - the artistic (musical) and technical (forestry engineering, wood processing engineering, mechanical and physical engineering) apparently opposite but which can be happily exploited for both parties. Thus, we can speak of a new paradigm of education through which art can combine with the technical sciences for the benefit of all. The aim of the paper is to present experimental methods in mechanical and acoustic evaluation of violins from engineering and artistic perspectives. The presented results are part of a larger study carried out within an experimental demonstration research project.*
Key words: *experimental methods, engineering, musical instruments, artist, acoustic quality, violin*

1. Engineering issues

From a constructive and functional point of view, the strings musical instrument body is a structure with thin walls having the role of amplifying the musical sounds. For instance, violins are constructed of numerous elements having an acoustic, functional or aesthetic role (Figure 1a). The violin consists of two subassemblies: the resonance box (violin body) and the sound generation system consisting of strings, neck with the tailpiece and the bridge. The violin body consists of a top plate, a back plate, the ribs and the linings with thicknesses about 100 times smaller than the overall dimensions of violin body (Figure 1b). The transfer of the vibrational energy of the strings is done from the vibrating string to the bridge to which the strings are fixed. It propagates the vibration to the sound board (top plate) which begins to vibrate, entraining the air inside the body [1–4].

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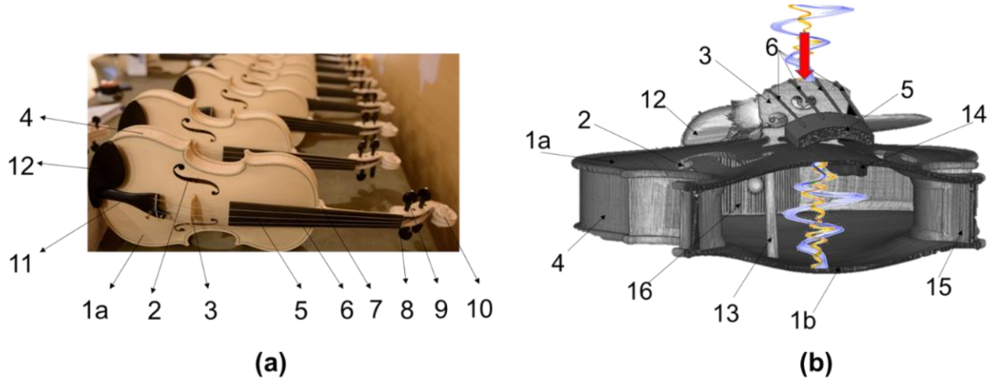


Fig. 1. The violin. Legend: (a) Structural components of a violin (1 – the top plate; 2 – sound hole f; 3 – bridge; 4 – sides; 5 – fingerboard; 6 – strings; 7 – neck; 8 – top nut; 9 – pegs; 10 – scroll; 11 – tailpiece; 12 – chinrest); (b) 3D cross section through the thin-walled structure of the violin body - computer image tomograph

Due to the longitudinal and transverse vibrations of the plates, as well as the vibration of the air in the cavity, the oscillating movement is transmitted to the sides and the back plate which in turn introduces into the system an oscillating movement of air inside the body (Figure 1b). Thus the air pressure in the thin walled structure changes periodically, acting as a Helmholtz type resonator. Taking into account the contour conditions, the sound waves are reflected and radiated by the walls of the box in all directions, producing the composition of sound waves under a rich spectrum of harmonics. The body of the guitar converts the high vibration pressure from the string into the low pressure vibrations of the ambient air, thus achieving a phenomenon of "impedance equalization". The speed of propagation of sound waves through solid media (string - string - plate - box) is higher than that through air, which is why the mechanical structure of the instrument influences the acoustic quality [5]. The top plate is always made of resonance spruce wood (*Picea abies L. Karst*). The back plate is usually made of curly maple wood (*Acer pseudoplatanus L.)*, but alternative species can be used as well [5 - 8].

From a geometrical point of view, the top and back plate have variable thickness, and the shape of the middle surface is curved both in the longitudinal and in the transverse direction. The violin is a complex structure which undergo small amplitude vibrations and has a multitude of vibrational modes. Each mode has a resonant frequency, a damping factor, a mode shape and a radiation efficiency pattern [6 - 10]. Pioneering work on the modes of vibration of violin plates was initiated by Hutchins (1962) [9] for defining the modes of vibration of plates. The main task of the violin maker is to use technological operations to control some of the parameters of the vibration modes. It is worth mentioning that in the audible frequency range the violin has numerous vibrational modes.

Figure 2 (a) shows input impedance measured at the bridge versus frequency of two famous violins, the Titian Stradivari (thick line) and the Plowden Guarneri del Gesu (thin line). The signature modes of these violins are referred to by [10] as cavity modes (A0, A1), corpus modes (CBR or C bouts rhomboidal), main body resonance (B1- and B1+). There are two low frequency modes associated with the pressure variation in the cavity of the violin box, AO and A1. A0 and A1 are coupled modes. A0 occurs around 270 Hz and is called the Helmholtz resonance. A1 is a first standing wave in the length of the box typically occurring in the range 470 – 490 Hz and is the response of the structure to the "inflating" and "deflating" of the upper and lower bouts. CBR - is the lowest corpus frequency mode at around 400 Hz [10]. The first bending modes B1- and B1+ are at around 500 Hz and both radiate energy by themselves.

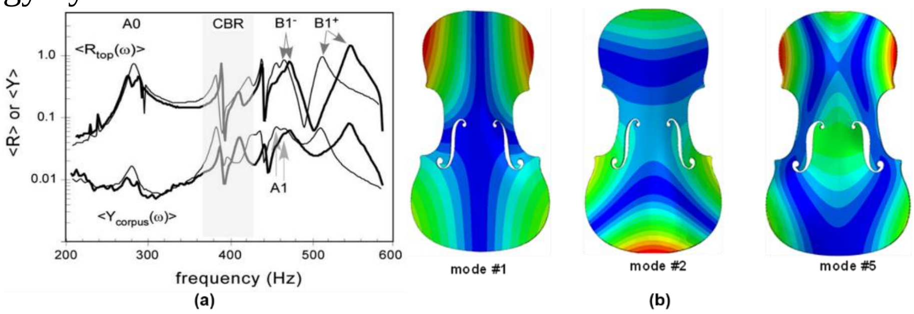


Fig. 2. The violin plate a) the signature modes of a violin: A0; A1; CBR; B1-; B1+ (Signature mode region OP (log) corpus mobility (Ycorpus) (lower curves, m/s/N) and top hemisphere (log) radiativity (Rtop) upper curves, Pa/N for Titian Stradivari thick line and Plowden Guarneri del Gesu thin line vs frequency [10]; b) Modes of vibration of violin plates: mode #1 twisting, mode #2 bending, mode #5 ring mode [11].

As mentioned by Bissinger 2008 [10], "Each violin has only five "signature" corpus +top+ribs+back normal modes in the open string region. Sometimes the tailpiece or neck-fingerboard substructures can couple to these modes, splitting them. The violin's open string region 196–660 Hz for A=440 Hz is crucial to the sound of the violin and is also where the lowest plate modes are most important. Above 700 Hz when the violinist holds or plays the violin the total damping increases so much that modes overlap. The previous description of the low frequency individual modes of the violin body is important for delimiting the frequency range in which the violin maker, through manufacturing, can seek to control these modes and implicitly to control the sound of the violin. Stanciu et al 2020 [11] investigated the vibration modes of unattached plates of violin using finite element analysis, obtaining the natural frequencies and the main modes as can be seen in Figure 2(b).

At the same time, experimental studies have shown that, under the long action of the vibratory forces of the strings, in the sub microscopic structure of wood there are changes that lead to the stabilization of other values of the acoustic properties of the resonant wood [12 – 13]. In this regard, we can speak about the memory of wood. Wood consists of three states: solid state (wood substance), liquid state (water, bound water, substances produced by the parenchymal cells) and gaseous state. Thus, when an external force stresses the wood material, an oscillatory motion develops in the composition of the cell membrane that changes the position of the crystallites in the cellulosic fibers. The changes in the position of the crystallites must overcome the intermicellar attractive forces and the viscosity of the water film (bound water), these being proportional to the number of crystallites existing in the mass of the unit volume [8]. The temperature increase reduces the internal attractive forces and the viscosity of the water film between micelles, leading to the decrease of the internal friction and to the change in mechanical and acoustic properties [8].

2. Manufacturing issues

Although it is considered that the violin has reached its architectural perfection with the famous productions of the Cremona violin school, constructive improvements are still possible, which will improve the sound performance of the instrument. The violin is a very complex musical instrument, consisting of over 60 components. The manufacturing technology comprises more than 80 operations, which rely both on modern processing techniques, and on manual craftsmanship gained over many years of experience, especially in the case of Maestro violins. In some new technological operations, manufacturers are always trying to establish a way in which wood yield is improved, starting with wood sorting and establishing the functional role of each piece of wood resulting from primary cutting and ending with wood finishing processes. A brief presentation of the technological sequence of operations specific to violin making is illustrated in Fig. 3.

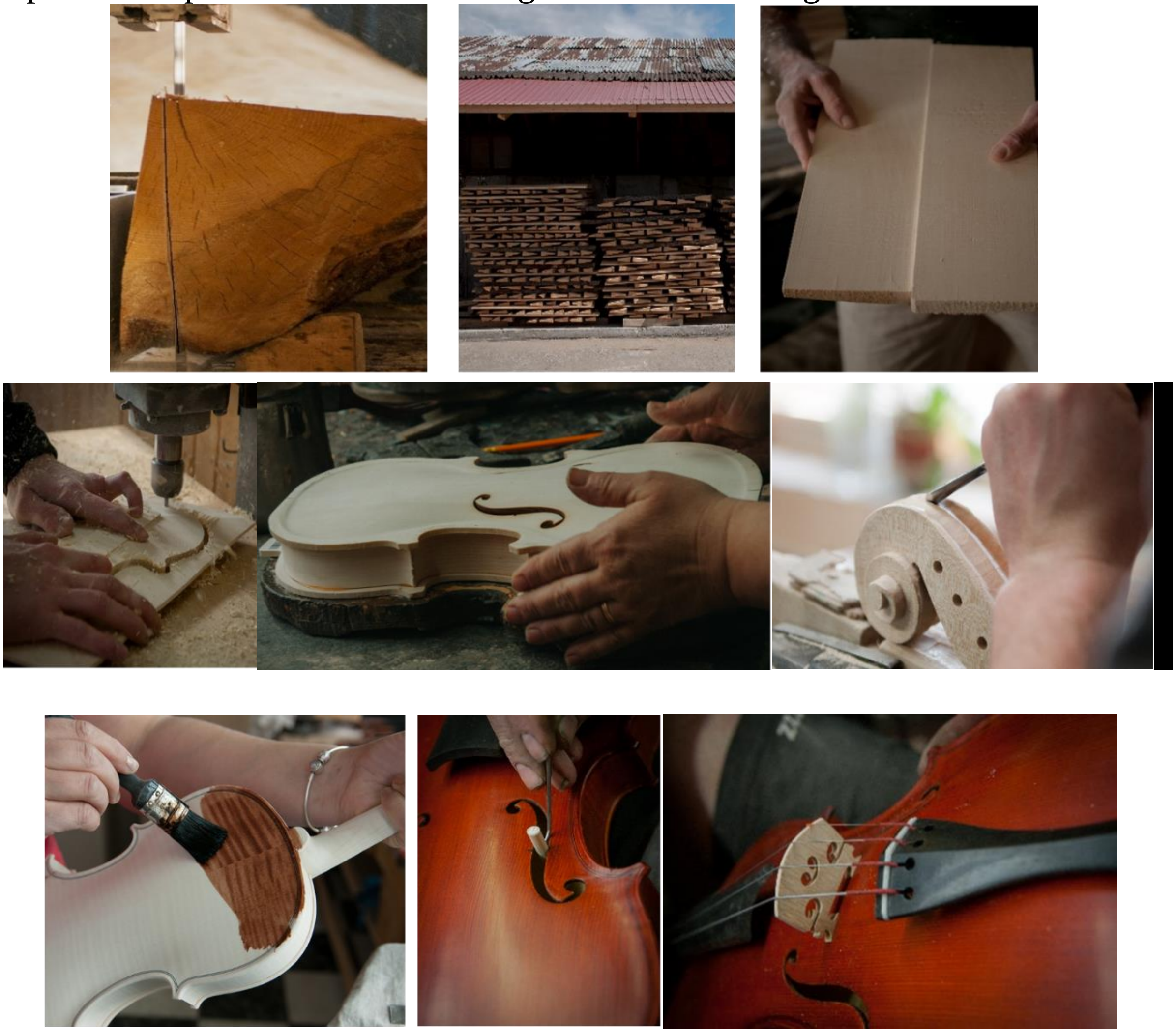


Fig. 3. Technological operations (selection) for the manufacturing of a violin (Photos by Gliga Vasile Ghiorghe and AP Studio Brasov)

3. Acoustic and artistic issues

In the final phase of checking the acoustic quality and ergonomics of the musical instrument, the instrumental artists are involved through activities of interpretation and testing of instruments or musical auditions on new instruments, completed or in different stages of completion [14 – 17]. Thus, their knowledge, skills and talent, musical ear, artistic feelings produced through the tested musical instruments are quantified in artistic terms and subsequently correlated with the processing of recorded acoustic signals. In a first stage, a set of criteria for selecting a quality violin was extracted from the literature and by consulting the violinists based on a survey.

Quality sound criteria

- *The bright and strong sound* refers to the quality of the sound produced by the instrument, a sound that is very penetrating and open, being able to cover with the harmonics produced, a large performance hall.
- *The clarity of sounds* is determined by the vibration of the strings that produce very clearly identifiable, isolated sounds, without mixing with the vibrations of other sounds.
- *The warm, silky sound* is that velvety sound that caresses the hearing and that determines a relaxation and pleasure to the listener. A violin can have both warm, silky and bright sounds, depending on how the musical text is interpreted. But there are also instruments that have soft and warm sounds, but which have the disadvantage of not entering large concert halls.
- *The amplitude of sounds* refers to the way in which the sounds of the violin pass or not very far, being able to cover larger or smaller rooms. It all depends on the amplitude of the wave and the distance between the points with the highest vibration. It is measured in units of decibel (dB).
- *Equal sound on all 4 strings*. To determine that a violin is equal on all 4 strings, it is played in turn on each string, with the same pressure and bow speed, and listens very well if all strings respond the same, with the same colour, the same timbre, and the same intensity. It is also observed if each of the 4 strings responds just as easily, with the same minimum of effort.
- *The timbre colour*. Each violin has its own timbre, a quality of sound that characterizes it. It is very difficult to describe the timbre in words, but we can think of various colors that could characterize the sound of each violin. A stamp can be: bright, soft, strong, shrill, dry, etc.

Criteria related to sound production

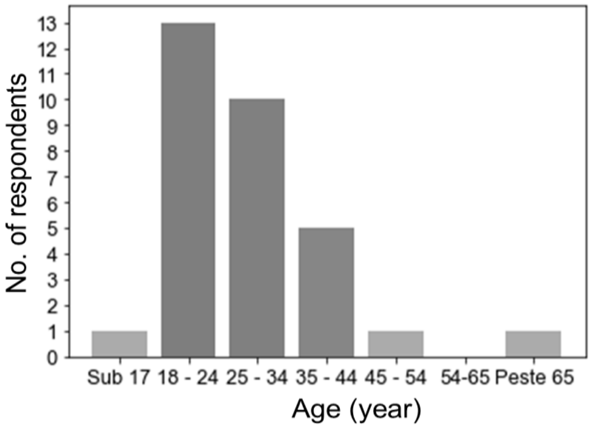
- *Easy sound perform* refers to the way in which the instrumentalist can perform the interpretation of a piece, with a minimum of effort. It is about the ease with which sound is produced without excessive pressure of the fingers or the bow on the string and the way in which the sounds can be sustained to achieve a crescendo or a strong dynamic.
- The small pitch. When a violin has a small "pitch", it means that the distance between the fingers in the case of a semitone, for example, is smaller than in the case of a violin with a larger pitch. This small step can be an advantage for those who have a smaller hand with shorter fingers, but can be a disadvantage for people who have thicker fingers, especially in high positions.

Criteria related to accessories and constructive appearance

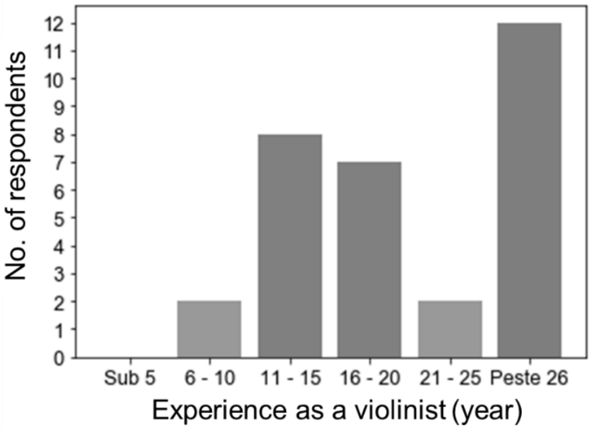
- *The distance between the strings*. Normally, the distance between the strings is about 1.1 cm, but there are people who prefer a greater or lesser distance, depending on the thickness of the fingers. A shorter distance between the strings favors obtaining musical tuning of 3 and 4 sounds, instead it can cause other strings to be accidentally touched, which requires more attention to the chord planes (positioning the arm of the right hand above or below, depending on each string).

- *The height of the bridge*. The bridge adapts depending on the quality of the strings (softer or stronger), and the interpreter's preference to have a greater or lesser distance between the strings and the keyboard.
- *The quality of the strings* is crucial for obtaining the sounds of the violin. At the moment there are a lot of types of strings, which meet the preferences of artists with different levels of resistance and sound qualities.
- *The accessories (fixtures, chin, double chin)* matter a lot for the comfort of the performer and for the sound of the violin. Any metallic element can damage the sound quality of a violin, in this case it is recommended to use at most 2 fixtures on the violin and the double beard and beard with as few metallic elements as possible, but also adapted to the conformation of the instrumentalist (neck length and thickness, structure bone of the face and chest (where it is touched with the double chin) Important elements in choosing the double chin and chin are: elasticity, size, shape, height and the material from which they are made (softer, stiffer, etc.).
- *The position of the soundpost* is also very important for the sound of a violin. In this sense, the violinists try to position it several times, until they reach the final one, which leads to obtaining the most beautiful sound that the respective violin can have. In the case of the soundpost position, the responsibility of positioning it lies exclusively with the luthier.
- *The bridge positioning in relation to the fingerboard, the quality of the bridge wood, the thickness of the violin fingerboard, the height of the violin fingerboard.* All these important criteria belong the violin maker. These technical details produce differences in the sound of the violin, so that a maximum effort is made by the violinist to find the best combination between the above elements, in order to obtain the maximum quality of the instrument.
- *The age of the violin.* The older the wood of the violin, the higher the sound quality of the instrument.
- *Belonging to an internationally recognized violin makers.* It is well known that the violins of old violin makers such as Amati, Stradivari, Klotz, etc. are emblematic, because these violin makers have invested time, research and science in creating violins of a very high acoustic quality. Each of them had different measurements, proportions, construction methods, special gluing glues, varnishes, etc., creating its own model, recognizable by its uniqueness and quality.

The survey conducted to select the most important criteria was attended by 31 people, mostly women (64.5%) (Figure 4, a). The predominant age category is 18-24 years, but only 3 people are outside the range of 18-44 years (Figure 4, b). All participants have an experience of at least 5 years of playing the violin, the predominant category being those with over 25 years of experience (38.7%) (Figure 4, c).



a)



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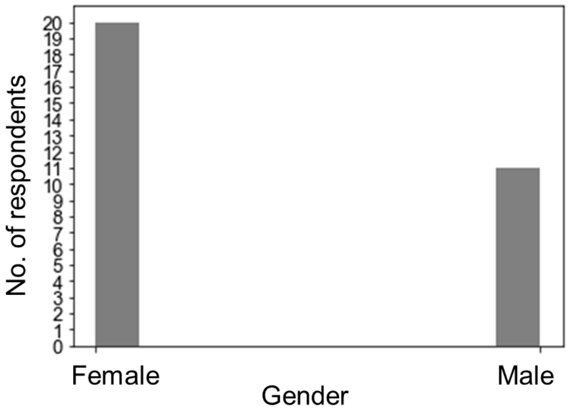
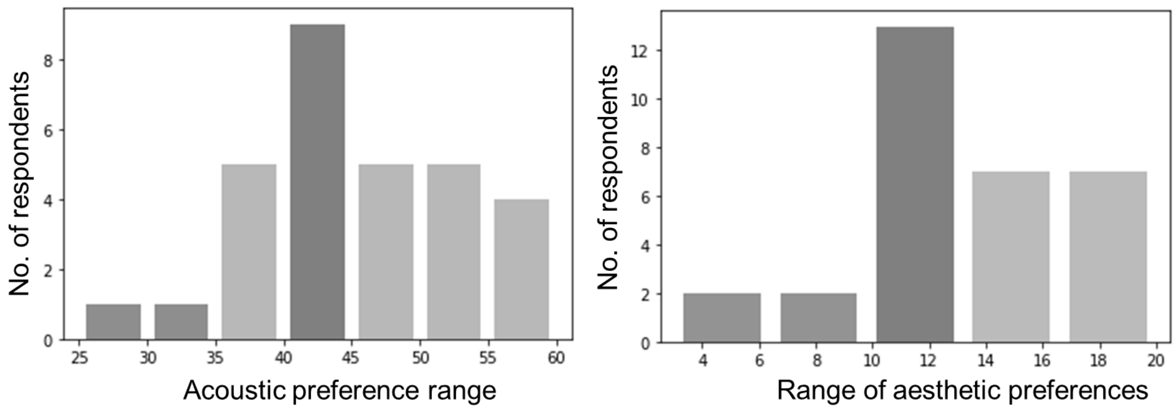


c)

Fig. 4. Statistics on the experience, age and gender of respondents

Each criterion was evaluated with one of the 4 options (“do not answer” = 0; “irrelevant” = 1; ”relevant” = 2; “very relevant” = 3). From the point of view of acoustic preferences, the list of the first 4 parameters, calculated according to importance are: clarity of sounds (2.8); warm sound (2.67); positioning the soundpost (2.61); string quality (2.52). With an average of 2.5, at par, the following 4 parameters were chosen as very relevant criteria regarding the acoustic quality of the violins: bright and strong tone; amplitude of sounds; timbre colour; equal sound on strings. From the point of view of aesthetic preferences, the list of the first 3 parameters, calculated according to importance, are: uniform varnish (2.1); matte or lacquered appearance (1.96) and the size of the violin (1.74).

Final, all the scores given by each person to the acoustic/aesthetic preferences were added up, then that person received that score, we consider the score a kind of estimate of the person's interest in these aspects - for example, a higher score great in aesthetics - the person gives more importance than others to the various parameters considered in the aesthetic field. Tor a response type ”no answer” the score was considered equal with zero. The scores were then grouped into intervals. The histogram shows the number of people in each range. The following two histograms consider all people, regardless of gender (Figure 5).



a) b)

Fig. 5. Statistics on acoustic/aesthetic preference criteria reported to number of respondents

4. Conclusion

It can be concluded that in any mechanical structure with acoustic role such as musical instruments, the collaboration between engineers, designers, producers and final beneficiaries - instrumental artists, is imperative, each contributing to increasing product quality and end user satisfaction, as well as society, through the cultural / musical education that artists provide with dignity, dedication and passion.

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