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An aid to innovation in instrument-making: a collaborative approach between workshops and research laboratories

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ABSTRACT

The economics of French instrument-making is mostly made up of very small handicraft enterprises. But craftsmen do not always have the means to embark, by themselves, on an innovation strategy. The idea is to try to respond to current challenges in instrument making; for example, the reduction in costs of design times or the adaptation to customer needs. All of this necessitates the development of low cost tools for characterising and prototyping of instruments dedicated to their use in workshops. Examples of collaborative approach between instrument makers and research laboratories are presented.

Mainly, the PAFI project, for “Instrument-making Aid Platform” aims to develop characterisation tools for all the instrument families. The initiative’s originality lies in the fact that “pilot craftsmen” are associated with every stage of development. The process involves a research program and the support of craftsmen for developing the hardware and software. Bearing in mind the international economic context, these experiences may act as a basis for broadening and pursuing this initiative on an international scale. The open and progressive nature of the work means that we can consider such a prospect with a view to maintaining the small-scale production of high-quality instruments.

1. INTRODUCTION

The economics of French instrument making consists almost entirely of very small handicraft enterprises. Faced with strong international competition, they are positioned on the top-end and concert musical instruments market, while learning instruments are rather manufactured on an industrial basis. This observation may certainly be applied more generally at European level, and even at international level.

The craft industry production of musical instruments is the result of a long process of learning know-how and optimising the instrument making stages. The development of traditional instruments is an ongoing process that occurs in response to the needs of musicians and composers (both contemporary and historic ones), or is imposed by constraints on the supply of protected materials, such as certain types of exotic wood. Consequently, the use of alternative materials, the modification of structural elements, and improvements made to intonation or acoustic instrument radiation are now carried out using scientific tools. While this approach is widespread for industrial applications, this is seldom the case within handicraft businesses.

The issue, therefore, is to develop tools for characterising instruments suitable for use in a workshop so that instrument-makers may have the means at their disposal for innovating by keeping their production quality one step ahead and their handicraft enterprises competitive.

How a response can be provided to the geographic and thematic dispersal of the craftsmen? The objective is to present some initiatives taken in France over the last few years in order to bring instrument-makers and research laboratories closer together in a structured, sustainable way and create a joint working dynamic. This illustration is provided based on the PAFI project (Instrument Making Aid Platform) – which is intended, for the medium and long term, to provide *low-cost* tools suitable for workshop operations and concrete responses to situations involving the innovation of musical instruments. What makes the process original is the fact that instrument-makers are involved in all the development stages, defining the specifications and testing the prototypes.

This paper aims to present an original approach to scientific and technical collaboration between a collective of craftsmen, manufacturers and repairers of musical instruments, a grouping of research laboratories, and a technology transfer and support structure for enterprises: Itemm,

“Institut technologique européen des métiers de la musique”.

This paper outlines the environment and the special conditions which led to this experiment. The issue of innovation as a part of instrument making is specific to the French context and does seem to have the capacity for general application at international level. So what is involved here is a presentation of examples of technology transfers that contribute to maintaining craft industry production of high-quality musical instruments. The paper shows how to provide instrument-makers with tools for innovating and improving instruments which are suited to their needs, and which are the outcome of scientific research over the last twenty years, particularly in the field of musical acoustics.

2. ECONOMIC BACKGROUND

Instrument making belongs to the cultural industries and now the leisure industries (technically speaking,

engineering and broadcasting of musical signals) which, by their very nature, require in-depth analysis of “musical sound” and the mastery of the cutting-edge technologies associated with it. Instrument making, by rights, constitutes one of the renowned economic sectors drawing directly on the results of scientific research, and particularly research in the field of musical acoustics and material sciences.

2.1. The music industry

The advent of electronic and digital technologies is bringing about far-reaching, drastic changes in the music industry and, consequently, instrument making, to the extent of deliberately using electronic accessories and even computers, as fully-fledged musical instruments. Historically speaking, the starting point for this change was the recurring issue of amplifying instruments which, over the last century, have been the outcome of new cultural practices related on the one hand to the growth of Afro-American music and then electro-acoustic music



Figure 1. Skilled-craft industry sector: services all around repair and maintenance of musical instruments, from manufacture to direct selling.

and, on the other hand, to the change in places where performance are provided and music is listened to, which applies to all types of music.

A consequence of this technological and cultural revolution has been a change in the landscape in terms of instrument making. From the second half of the 20th century onwards, the mass-manufacturing of musical instruments gradually moved from Europe to the United States of America, Japan, South-East Asia and now, China. This distribution is also to do with an industrial mode for instruments development (electro-acoustic and electronic instruments, among others) which began in the USA and was applied to electric guitars. It now impacts on all the instrument families, where a few major brands dominate the market, particularly in the case of electronic instrument making. Computer-assisted music and sound synthesis technologies provide examples of this perspective.

Along with the expansion of amplified forms of music, music-making is made accessible to all and worldwide cultural intermixing and have also brought about this change in the manufacturing sites for traditional acoustic instruments on the beginner and learner markets. For example, only instrument making that provides high added value has been retained in Europe, with a few “specialities”, like the piano industry in Germany and the wind instrument industry in France.

2.2. The skilled-craft industry sector

Although in this case the presentation is restricted to the typology applicable to French instrument making, it seems that the clear distinction between international industrial companies on the one hand and a network of very small handicraft enterprises on the other hand, reflects the situation in many countries.

It is quite difficult to obtain an accurate picture of the French instrument making sector. An overview of its economic activity leads to a current assessment of the number of companies involved as being around 2,500 (the manufacturing, restoration, repair, maintenance, tuning, servicing and marketing of musical instruments), providing a pool of about 10,000 jobs [1]. These figures tell us a great deal, because in order to fully delineate this instrument sector, all of the actors involved in the technical field must be taken into account: industrials, craftsmen, distributors, and music stores of a general or specialised nature with a repair workshop.

Musical instruments production, which is positioned at the top end of the market, now constitutes the output more or less solely of very small handicraft enterprises with fewer than twenty employees, two-thirds of which

are sole proprietorships. What is actually entailed in the sector is no longer just craft-industry or semi-industrial manufacturing, but the existence of structures engaged in “mixed” technical and commercial lines of business, offering repair and maintenance services along with customer advice and direct selling. Pools of rental instruments, which consequently require regular technical maintenance, are becoming increasingly important within this context (markets for learning instruments, particularly for young people receiving musical training).

The standard profile for a craft industry workshop, to a varying extent depending on the instrument speciality, is thus oriented towards a service offer ranging from the manufacture and repair of instruments (sometimes to a very high level of technical quality and know-how) through to marketing and maintenance, and even, increasingly, the finishing and adjustment of imported unfinished instruments, within the learning instruments market niche. The estimated number of companies with a repair workshop is between 1,600 and 1,800. The estimated number of enterprises with a recognised manufacturing line of business is nearly 800.

3. TECHNOLOGICAL AND ENVIRONMENTAL CHALLENGES

From a technical perspective, the basic characteristic of instrument making is the multidisciplinary nature of the skills which, quite often, are held by the same person within the company:

- Use of multiple materials (woods, metals, skins, textiles, composites);
- Mastery of related types of know-how (design, assemblies, finishes);
- Varied technical and scientific knowledge (of a mechanical, acoustic, or electronic nature, or relating to computer-integrated manufacturing);
- Various types of cultural knowledge (music, organology, instrument playing);
- And, of course, company management (supplies, inventory, trading, communication).

And this is not to mention the advent of electronic instruments and computer music technology. The international economic context is now imposing ever-greater integration of technological innovation, which handicraft enterprises are far from being exempt from. Quite to the contrary, keeping ahead in terms of quality demands (both on the products and the services that they offer) or, in other words, in relation to both “top end” and “customised” items, involves the intense

development of appropriate technical solutions and their quick implementation within the enterprises, following the example of the developments noted over the last thirty years in mass-production units in all sectors. The benefits derived from this are also the same:

- *Reduced costs and shorter design and execution timeframes* (virtual prototyping, selection of materials, reproducibility, production monitoring and control, etc.);
- *Capitalising on knowledge and practices* (products traceability, the optimisation and development of models, etc.);
- And, a key advantage for small enterprises: *adaptation to customers' needs* (response to specific demands, responsiveness, service quality, etc.).

Moreover, as in the case in a number of other business sectors, instrument making is also confronted with changes to standards and new regulations concerning workplace health and safety, or which relate to the themes of procurement and sustainable development. By way of an illustration, one of the major issues currently relates to the natural materials normally used for manufacturing musical instruments. Going above and beyond just the framework of restoring instruments that are collectors' items, international agreements for protecting flora and fauna concerning certain endangered species (CITES see [2]) are now adversely affecting the production of new instruments: the pernambuco used in modern bows and the rosewood used in guitars and percussion instruments, for example. In the medium-term, the precondition for maintaining a competitive craft industry production of high-quality musical instruments is not only seeking alternative high-performance materials (wood essences and/or composites), but also determining appropriate dimensions for their use in instrument making.

Thus, *combining the maintenance of traditional know-how and the use of innovative methods and means* currently lies at the heart of the challenges to be taken up by the instrument making sector [3]. In order to provide an effective response, we need to overcome the isolation of craftsmen and provide solutions that are of common interest to each family of instruments.

4. INNOVATION AND INSTRUMENT MAKING

The relations between music and science go back a long way. Instrument-makers have continually sought to understand how the instruments that they make work so that they can improve their performance and adapt

their characteristics to what musicians want. Moreover, advances made in research have already enabled significant spin-offs in terms of the characterization and sizing of instruments, and prediction and prototyping tools. Currently, instrument-makers even have products dedicated to instrumentation such as BIAS and VIAS, developed by IWK [4]. The initiatives presented here are not positioned as complementary tools. What is original about them is the collaborative approach adopted in defining them, which involved the instrument makers themselves.

4.1. Skilled-craft industry/research dynamics

Since 2001, annual meetings between luthiers and scientists have been organised by the Itemm with the support¹ of one of the main French professional associations, the UNFI (National Instrument Making Union). These meetings firstly devoted to stringed instruments², which are held over a two-day period, provide the opportunity to exchange information via specialised lectures devoted to musical acoustics, materials sciences (particularly "resonance" woods used in instrument making), as well as tutorials applying vibration and acoustics measurement equipment. These simulations provide an educational framework within which scientific ideas and concepts can be discussed, criticised, understood and adapted to the specific features of the instruments.

Among the various examples of tutorials carried out, the following may be cited for example: identification of the initial resonances and categorization of guitars using vibration measurements or determination of the wood characteristics based on the resonances of the bow sticks. From 2001 to 2007, many experiments were designed and presented. Their design and development involved more than sixty students from the acoustics training courses offered by Le Mans University (France). This potential enables responding to the concrete issues raised by craftsmen.

These interactions have been more widely and progressively extended to the whole French scientific musical acoustics community, implying particularly PhD student researches. Each current biannual meeting – one for string instruments and the other for wind instruments – has thus two main objectives: on the one hand a regular information about recent research results and, on the other hand, an agenda

¹ The sessions are also supported by the musical acoustics group of the French acoustical society (GSAM-SFA) since 2008.

² On the same basis, there are from now on such annual meetings devoted to wind instruments since 2010.



Figure 2. Biannual meeting participants (string and wind instruments): instrument makers and scientists joint working dynamic.

and a better definition of solutions to be found to efficiently help makers. Therefore, this dynamic contributes to the elaboration of a collective solutions and produces a common strategy aiming for global innovation improvement within the workshop.

4.2. Individual support

After six years of collaborative effort (2001-2007), the closer links between luthiers and university staff resulted in the development of a pilot metrology tool called *Lutherie tools*, developed by the “Laboratoire d’Acoustique de l’Université du Maine” (LAUM) and the “Pôle d’innovation des métiers de la musique” (music professions innovation centre³), Itemm. This system was made available to craftsmen free of charge, in exchange for feedback about using the tools. Above and beyond being a tool with predefined functionalities enabling a response to the needs identified. The main purpose of *Lutherie tools* was to provide luthiers and bow-makers with guidance concerning their thinking and their approach to characterizing their work.

As an experimental device, *Lutherie tools* consists of various equipment items (vibration and force sensors, signal conditioning box) and analysis software (developed with RAD framework Matlab® and distributed as compiled executables). It is intended for stringed instruments and is organized into specialized modules: the guitar, harp, quartet and bow. By measuring transfer functions, it enables instrument

elements, and even whole instruments, to be characterised and sized. The objective here is not to provide details of the system’s various functionalities, but rather to present the project’s development approach which was chosen [5].

Lutherie tools has an open design in order to respond to the issues specific to each instrument, and to enable developments of the various functionalities to be oriented according to the feedback obtained. One of the major advantages of the system is its low cost when it comes to ensuring broad dissemination within workshops. While some of the system’s functionalities are already to be found in commercial products used in the field of mechanical engineering, they are only available piecemeal and their complexity requires a level of expertise that most instrument-makers do not have.

Ten or so copies of the initial prototype of the device were produced in 2007, and then twenty or so in 2009 for the second version. The systems are loaned at professional meetings for a one-year period. Modifications are made based on the critical feedback provided. These loans are extended by being associated with a personal applied research project, formulated by each of the instrument-makers involved in the dynamics. Each individual project is supported and monitored over the current year and forms the subject of a presentation of the results at the next professional meeting. It has to be noticed that this individual support is essential to facilitate the adjustment of the educational process to the real needs of the makers and to obtain more detailed feedbacks to improve iteratively the forthcoming field studies and actions.

5. THE PAFI PROJECT

The PAFI (French acronym for Instrument Making Aid Platform) project, drawn up over a four-year period (2009-2013) and may be seen as the general

³ The name “Pôle d’innovation” (innovation centre) is awarded subject to a French Ministry for the Craft Industries quality label granted to an establishment for developing an economic and in particular technological support mission for a business sector. The Itemm, one of the main instrument making training centres at European level, is in charge of technology transfers for companies within this field in France.

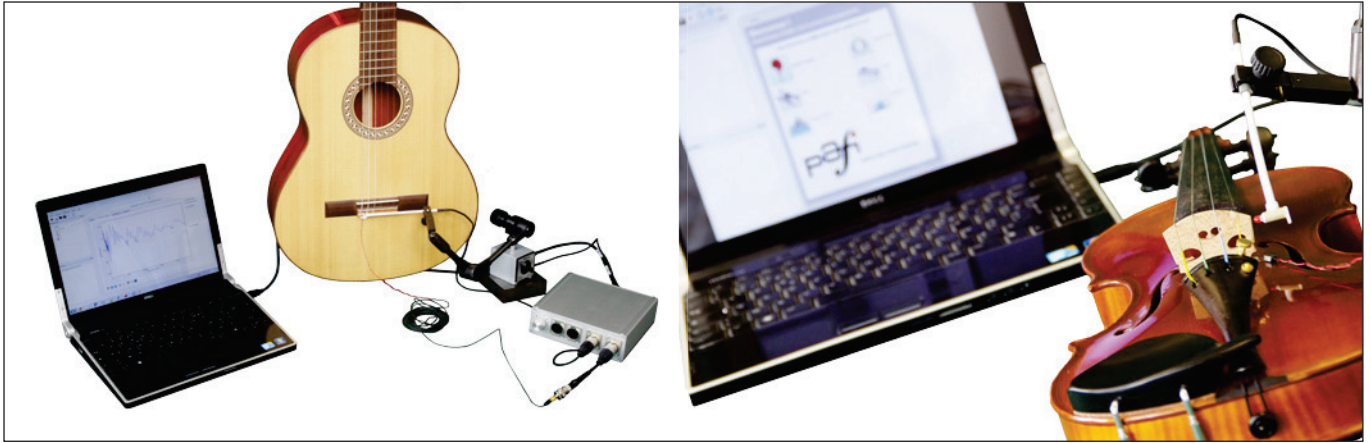


Figure 3. Stringed instrument device prototype (PAFI project): mobility measurement at the bridge. Transfer function measurements at the bridge give important information regarding instrument playing behaviour. It characterizes the overall coupling between the strings and the body by mean of equivalent parameters (see [6], [7], [8], [9]).

implementation of the *Lutherie tools* approach to all the families of instruments: plucked and bowed stringed instruments, wind instruments (woodwind and brass) and, on an exploratory basis, percussion instruments. The objective targeted is the implementation of a hardware and software platform for supporting the design and characterization of musical instruments. The major stake involved is to ensure the compliance of this platform's functionalities with the concrete needs of instrument makers and their seamless integration into their everyday activities.

5.1. Partners and objectives

The project forms part of an ambitious collaborative approach involving four scientific partners (LAUM, Ircam, Télécom ParisTech, and GSII-ESEO⁴), the music professions innovation centre (Itemm), and a group of instrument makers co-ordinated by the UNFI (National Instrument Making Union). The project's strength lies in this combination of skills. What is involved is not just the isolated approach of a single craftsman, but a shared dynamic aimed at the whole of the professional sector.

Currently, top-end instruments are manufactured on a craft industry basis. The difference in assessments made by musicians and instrument-makers from one instrument to the next relates to the aspects of sound emission, expressiveness, ease of playing, and the

manufacturing quality: the finish, sturdiness, tuning, etc. This complex concept, referred to using the qualifier "quality", turns out to be tricky to assess. The multitudes of factors which contribute to the development of a successful instrument make it difficult to seek ways to improve it. Indeed, the ideal instrument, as a target to be achieved, does not exist, and does not constitute an unequivocal concept regarding which musicians, instrument-makers and music lovers might agree on. On the other hand, certain aspects of instruments can be deduced by measuring them, such as improving the range, or optimising the accuracy, even though they are linked to judgements based on perception.

In terms of applied research, the project plan is to identify particular indicators which, by using objective characteristics for the instruments, make it possible to categorize and discriminate between instruments using automated methods. For example, these indicators come out of mobility measurements at the bridge of stringed instruments or input impedance measurements of wind instruments. For each of these two instrument families, this work is carried out by students completing their PhDs. It also involves seeing in what way the results obtained may be integrated into the craftsmen's various activities: checks on the reproducibility and quality of a manufacturing process, characterization for the purposes of replicating a reference instrument, design support for a new product, selection of materials and sizing, etc.

5.2. Organization and results

Each laboratory specialises in a field, such as in musical acoustics or in instrumentation for the equipment items (force, vibration or acoustic sensors) or in signal processing (traditional Fourier analysis and high-resolution methods). Engineers were hired to ensure the

⁴ LAUM, Laboratoire d'acoustique de l'Université du Maine; GSII-ESEO, Groupe Signal Image et Instrumentation de l'École Supérieure d'Électronique de l'Ouest; LTCl-Télécom ParisTech, Laboratoire Traitement et Communication de l'Information de Télécom ParisTech; STMS-Ircam, Sciences et Technologies de la Musique et du Son de l'Institut de coordination Acoustique-Musique.



Figure 4. Bow characterization device prototype (PAFI project): mechanical and geometrical parameters measurements.



Figure 5. Wind instrument device prototype (PAFI project): input impedance measurement. The input impedance, measured or calculated, is a quantity that gives important information regarding instrument playing behaviour. It characterizes air column resonances from a given bore geometry (see [13], [14], [15], [16]).

developments and provide support for enterprises. Indeed the project integrated craftsmen right from the time of the design of the products intended for them and the definition of specifications, through to the testing and prototype development. Ten or so “pilot craftsmen” representative of all the various types of instruments were thus selected. Very small instrument making enterprises do not have either the human or financial resources to purchase and adapt laboratory measuring tools. One of the major constraints of the project once

again is to find robust technological solutions at the lowest cost. It is not the purpose of these tools to find answers to everything, but rather to facilitate innovation within very small enterprises.

The organization of the platform is based on modules: a general module concerning signal analysis and synthesis (for listening educational purposes), and specialized “sector” modules within each family of instruments. The whole lot has to be linked to a

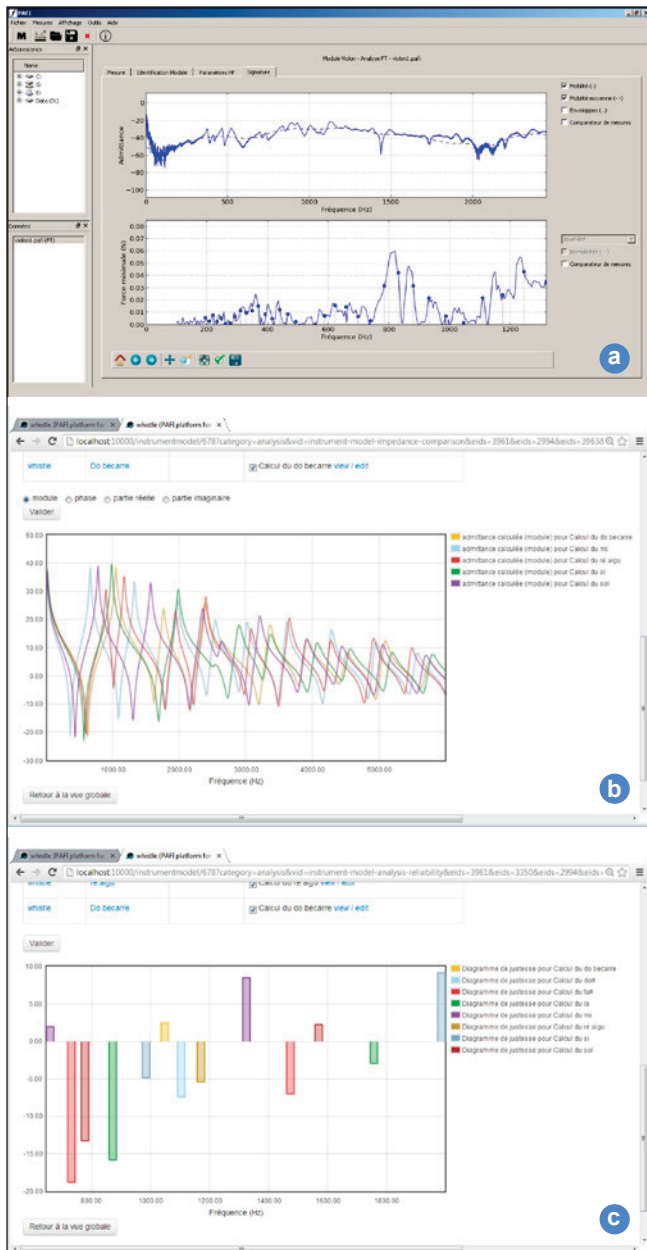


Figure 6. Analysis and calculating software prototypes (PAFI project).
 a) Stringed instruments software (Python-Qt technologies) – Up: Modulus of measured admittance at the bridge of a violin and its average value (dashed) – Down: Minimal bow force amplitude required to have the Helmholtz motion on the string. It can be seen as a playability criteria (for a given position and bow velocity).
 b) Wind instrument software (Python-HTML5 technologies) – Calculation (or measurement) of the input impedance for wood and brass instruments. In this example, several fingerings of a whistle are presented as modulus of the input admittance.
 c) Calculated whistle prototype intonation diagram deduced from input impedance.

database and a collaborative workspace on the Internet enabling information to be exchanged by the various users of the system. This pooling is intended to make it possible to provide a response to the isolation of craftsmen and create a dynamic that promotes innovation and maintenance of know-how. Simply making such a device available is not enough, and it is

foreseen that craftsmen will be trained via training courses organised by the Itemm.

For stringed instruments, a vibrating properties identification methodology of mechanical structures has been developed, whether the object is a musical instruments or not [6], [7], [8], [9]. This methodology has been implemented on several applications: guitars categorization, changes in shape or size of violin bridges analysis, evaluation of different types of guitar bracing, etc. A specific work has been conducted on violin bows in order to ascertain the influence of mechanical and geometrical bow parameters in playing situations [10], [11], [12].

Concerning wind instruments, studies have been logically focused on the exploration of information given by the input impedance in several practical cases [10], [11], [12], [13], [14], [15]. More specifically, the deviations between resonance and playing frequencies have been analyzed. The different methods for calculating the input impedance of an instrument have been compared and put to the test of measurements. With the craftsmen feedback, the scope of the methods have been tested on practical fields such as the influence of pad “resonators” (as the makers named it) on wind instruments keys or the bore reconstruction of a bassoon crook.

The platform is intended to be upgradable and open so that it can be used as the basis for future complementary work. For example, in light of the fact that the scientific results have already been published, it is foreseen that the analysis and calculation software will be published subject to a *free licence* or on an “open source” basis. The aim is to be able to easily integrate new functionalities and to establish a common purpose that may be developed more largely.

6. INTERIM ASSESSMENT, PROSPECTS

This paper presented collective initiatives for technological support to SME involved in instrument making currently under development in France. A lot of work is still to be achieved. Nevertheless, the first results are very encouraging. They enlighten the creation of a virtuous circle of synergy and collaboration between the instrument-making actors and the scientific community.

Upon completion, it is possible that these experiments may serve as a work basis to the general implementation and continuation of this dynamic at an international level. Indeed, in the light of the general typology of handicraft enterprises and the open, upgradeable nature of the work, this prospect may be considered and is even propitious for maintaining the craft industry production of high-quality musical instruments.

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