# 3D Printer Technology and Violin Making Tradition: an Outlook on Potential Applications and Open Questions

## Introduction

In recent years there has been growing interest in the area of musical instruments, stimulated by the marked rise in market values. In particular, most of the economic investments are focused on violins [1][2]. Their economic value is due to many factors such as their history, the intangible value of their sound, and the myths associated with the greatest lutherie's masters.

Many historical instruments made by Stradivari, Amati, Guarneri, and Guadagnini are still played, and many others are preserved within public museums. The particular sound of these instruments depends partly on the musician who plays them, but primarily on the intrinsic characteristics of the violin. This is closely related to the design, the making technique, the varnish finishing, and the set-up, established a priori by the violin maker.

The structural complexity of the violin and the difficulty of obtaining permission to perform scientific analysis have helped to maintain the mystery of what makes the sound of the historical instruments so suggestive, feeding the myths even more.

Currently there are only a few scientific contributions published by international scientific journals relating to antique musical instruments. However, in recent years a portion of the contemporary lutherie community has demonstrated great curiosity about the area of applied research, recognizing it could be a means to rediscover the "know-how" of the masters. They believe that non-invasive characterization of historical materials and the modeling of geometries and shapes, could enable the modern luthier to modify his or her technical approach, perfecting it more and more.

The aim of the scientific research is thus the reconstruction of working processes followed by the ancient luthiers through a comparison between the analytical results and the bibliographic historical sources. Today the new Museo del Violino in Cremona hosts two laboratories of applied research at the University of Pavia and the Politecnico di Milano. Their teams of scientists are involved in the study of the historical instruments of the museum collection in order to put the contemporary violin maker even more in contact with the knowledge of antique violin making methods.

The non-invasive diagnostic laboratory of the University of Pavia uses scientific facilities specifically adopted for these purposes, including VIS-UV photography, endoscopy, X-ray digital radiography, stereoscopy, FTIR reflection spectroscopy, X-ray fluorescence (XRF) spectroscopy, and 3D laser scanning. Of particular interest to the violin making community is the possible opportunity to obtain 3D models of historical musical instruments via the 3D laser scanner and create some parts of them using a low cost 3D printer. Information gained with these non-invasive techniques would change the rules for the enjoyment of these repositories of cultural heritage in the safest possible way.

The laboratory is currently developing a method for the acquisition of musical instrument 3D models and performing trials of printing sections of these models with a desktop 3D printer.

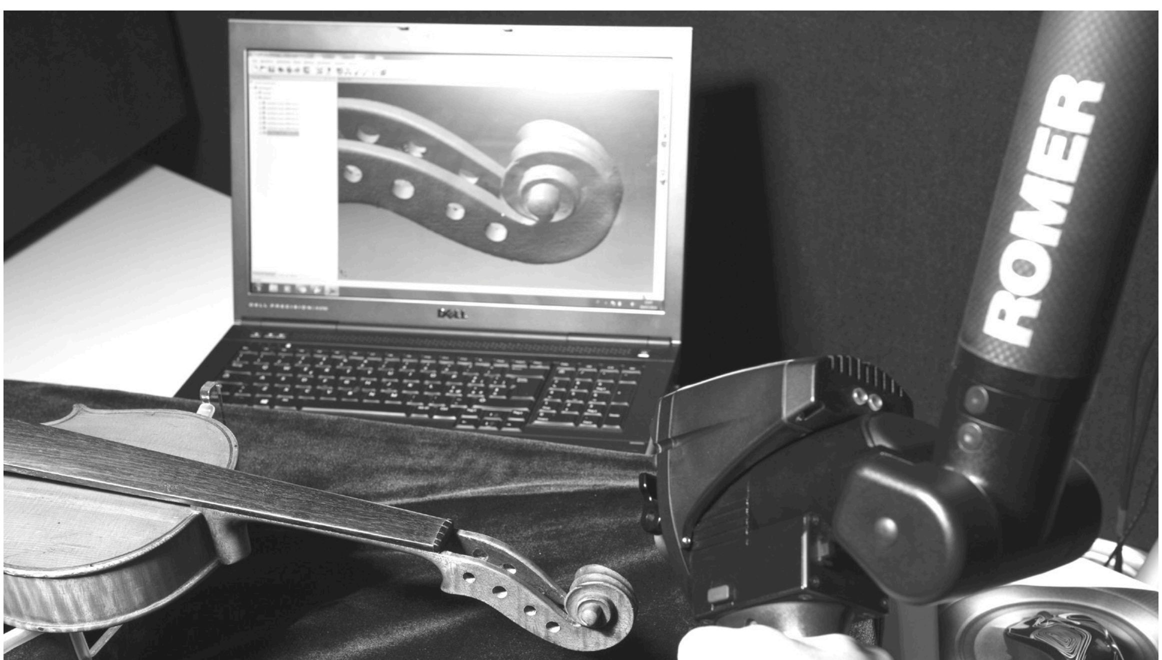


Fig.1.

3d scanning of the violin neck scroll.

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**3D Laser Scanner Modelling and Desktop 3D Printing in Lutherie**

The 3D laser scanner of Hexagon metrology equipped with the ROMER absolute arm is a measuring instrument which allows the acquisition of a three-dimensional model of a musical instrument with a resolution of 20 microns. For scanning, the violin is located on two different plexiglass stands, protected by a sheath of silicone. The arm has a high degree of freedom of movement, thanks to the seven rotational axes. A measuring head which emits a pulsed laser line is used to scan like a brush stroke the surface of the violin (Fig.1).

The obtained raw data consist of a points cloud in a three-dimensional space, which is transformed by Polyworks software in a mesh of polygons (polymesh), which creates in the model. The final polygonal model is true to the original in size as well as in the tiniest features and surface discontinuities. These features make the models better than those acquired through structured light 3D scanners.

The device allows one not only to virtually document the conservation status of a musical instrument, but also to extrapolate sections, forms, archings, and “stylistic” references (like the neck scroll or the corners) simply from the three-dimensional model. And all of the data will be exportable in different extensions editable by other CAD or CAM softwares.

Such information has great importance for the violin making community, which is always referring to sections, archings, and forms that have been passed down from master to apprentice over time. Especially as these measurements are far more accurate than were previously possible.

In addition to the analytical studies and data archiving of the scans, the laboratory is also using a desktop 3D printer in order to investigate the potential of the 3D printing process to reproduce portions of musical instruments. To do this, the polymesh is edited, closing the open surfaces in order to obtain a solid model exported in the STL format. This is then processed by the open source software Slic3r [3] in order to convert it in the .gcode format, readable by the 3D printer software.

The team currently uses a “replicant” REPRAP Prusa Mendel 3D printer, a low-cost prototype 3D printer based on an open access project of REPRAP copyright [4] (Fig.2).

The device is a desktop 3D printer that works according to additive manufacturing through the FDM process (Fused Deposition Modeling), extruding an atoxic and biodegradable plastic polymer like PLA (polylactate). There are some limitations due to the dimensions of the plate and consequently the size of the object we can create.

For this reason we decided to print only small parts important from a stylistic point of view, like the neck scroll. The duration of the printing process can be changed by the user, determining the final resolution of the object printed. From a slow process (6 hours) it is possible to obtain the 3D shape of a neck scroll with horizontal slices of 100 µm in thickness and lateral resolution less than 100 µm. This allows us to get an object nearly identical to the original in details and size (Fig.3).

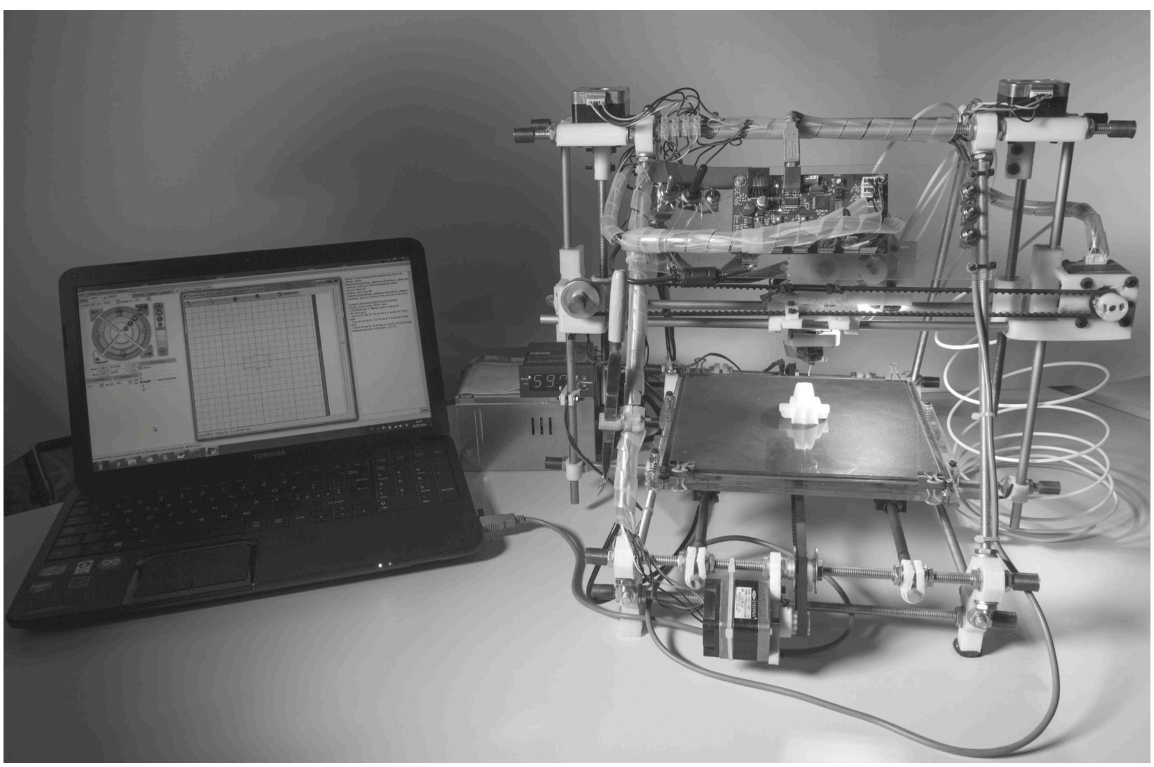

Fig.2.

The REPRAP Prusa Mendel 3D printer printing a small part of the neck scroll.

With printers of larger size it would be possible to print the soundboard, the back, the neck, or the set parts of the musical instrument. Complex three-dimensional objects can be also obtained with other technologies and at a higher resolution, but with much higher production costs (CNC, stereolithography etc.).

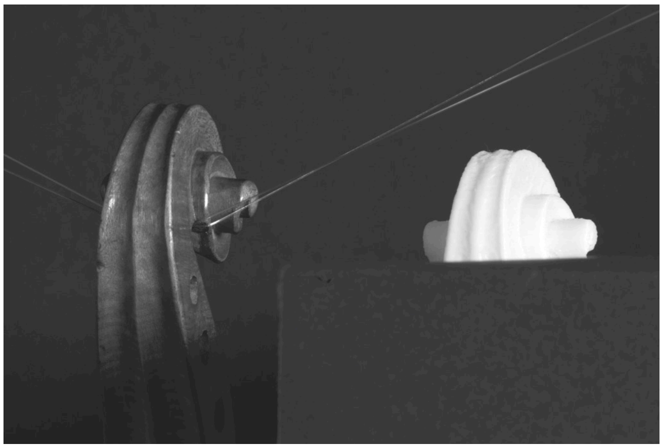

Fig.3. A violin neck scroll with its PLA printed copy.

Obviously, the ability to produce models or printed parts of important artworks such as portions of Stradivari or Guarneri violins can create problems depending on the use of this kind of data. For instance, with a printed model of a Stradivari neck scroll private luthiers could make a perfect copy of the original neck scroll giving them an evident commercial advantage compared to other craftsmen. It also creates a debate on the originality of the end product. This "open question" must be discussed by scientists, conservators, and owners of the violins, or other artworks, in order to regulate the commerce and to control the use of the data.

**Potential Applications**

One of the most important consequences of the digitization of cultural heritage lies in the possibility of setting up a permanent archive of data that describes the morphological characteristics of surfaces of three-dimensional objects. Currently many museums offer virtual tours for the remote enjoyment of their collections, and some of these already offer the download of 3D models which could be home-printed with a desktop 3D printer [5].

The opportunity to explore at home the smallest details of a Stradivarius violin would fascinate both the public and the community who work in the field of violin making. 3D technology allows the luthier to get closer to what he has always seen inside a museum glass case, and remote access democratically opens cultural heritage, including musical instruments, to all.

Introducing low cost 3D printing technology in the luthier's workshop could have a significant effect on the violin market. Such a scenario would require a strict ethical code for the use of the "printable" data, but simultaneously would open the doors to a new era for violin making.

**Conclusions**

Antique musical instruments, and in particular Cremonese historic violins, have always been a source of inspiration for violin makers, who study every smallest detail in order to understand the secret of their sound. The research team of the non-invasive diagnostic laboratory of the University of Pavia, hosted inside the new Museo del Violino in Cremona, is using new technologies for the analytical study of the museum's historical collection. In the interest of sharing with the artisans, all results are discussed with the violin making community.

One of the research activities within the laboratories is the 3D modeling of violins through a 3D laser scanner. Moreover we are experimenting with the possibility of 3D printing some parts using a low cost desktop 3D printer. All of the violins examined are subject to conservation authorization.

The future creation of a virtual data platform containing this extraordinarily useful information would also require discussion of the protection of the uniqueness of cultural heritage. Regulating access to information about the measurements and forms of historical musical instruments would meet the needs of the violin community to understand the style, the technology, and the shapes of the most important violins in the history of music.

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