COMMUNICATIONS

Adding a New Dimension to Woodwind Instrument Making, With a Little Help from Our (Tech) Friends

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Researchers who study historical wind instruments often find their work made more difficult, as museums and some private collectors do not allow their instruments to be played.

The question of allowing instruments to be played has been a matter of discussion for many decades. On one hand, it is felt that blowing warm, moist air into an antique instrument may damage it and should be avoided, as recommended by CIMCIM.[1] On the other hand, it is felt that musical instruments are intended to be played and to sound and should continue to be played, albeit under controlled conditions. A famous example is the Bate Collection at Oxford University, where students are allowed to play (and even borrow) many of the instruments. Different collections have a range of guidelines between these positions.

Some collections do not even allow researchers to measure instruments. In many cases where measurement is allowed, metal measuring instruments are forbidden, as it is felt that these could damage the wood. In some cases, even plastic tools may not be used as it is felt that these are also capable of damage if used incorrectly.

The main problem for would-be makers of reproductions is that, by excluding data like pitch, intonation, and sound quality from a research process, this specific and intrinsic information is lost to the researcher; if an instrument cannot be played it is impossible to determine its usable pitch or its sound and playing characteristics and qualities. If an instrument cannot be measured, then it cannot be copied.

1. The CIMCIM (Comité international pour les musées et collections d'instruments et de musique / International Committee for Museums and Collections of Instruments and Music) published some musical instrument handling guidelines: http://cimcim.mini.icom.museum/wp-content/uploads/sites/7/2019/01/Newsletter_10_1982.pdf; see pp. 31–2.

Until recently, musicians, scholars, and instrument makers traveled the world to see and, if allowed, try original instruments in collections and museums, and would eventually copy an instrument that seemed to fulfil the maker's needs in the best way. In the case of woodwind instruments, copying these exactly in the traditional way (using a lathe and reamers, for example) is sometimes impossible because of deformation that affects many wooden objects over time, including distortion of the bore. These irregular bore shapes can be measured but cannot be copied, either with traditional or modern wood machining techniques. Also, if one copies an original, it is often difficult to get feedback from the original artifact after copying it.

Since the beginning of the early music movement employing historical instruments, musicians and instrument makers have been searching collections for "ideal" historic examples to copy. Over time, the early music world developed for itself a kind of canon of instruments that are best to copy, for use in specific repertoire. This practice arose because developing new prototypes of historical woodwinds is time-consuming and can be costly if many reamers have to be made; sometimes these reamers are produced, tried, and used just one time (because they are not good enough), resulting in a significant waste of time and money.

New possibilities have recently become available through 3D printing techniques, which allow the production of very accurate prototypes and experiments in a quicker and cheaper way, without the need for reamers. In a familiar first step, one measures the instrument as fully as possible, often by hand;[2] these data are entered in a computer file which can be printed mirroring the original, or from which a flexible 3D model can be extracted.

The quality of the 3D-printed model and its properties will depend on the accuracy of the measurements, but also on the chosen printing method and material. A large palette of printing methods and materials is available in 3D printing, from sandstone to glass; finding the correct printer and medium for the project at hand is crucial. Plastic polymers are not the only option, but they tend to be more accessible, flexible, and cost-effective, all good reasons for their general use in this area. In addition to their precision, well-chosen polymers can even have a similar inner

2. Electronic and digital techniques to measure the bore exist, but these devices often cannot be used for an oboe's top joint, with its minimal bore of 4–6mm.

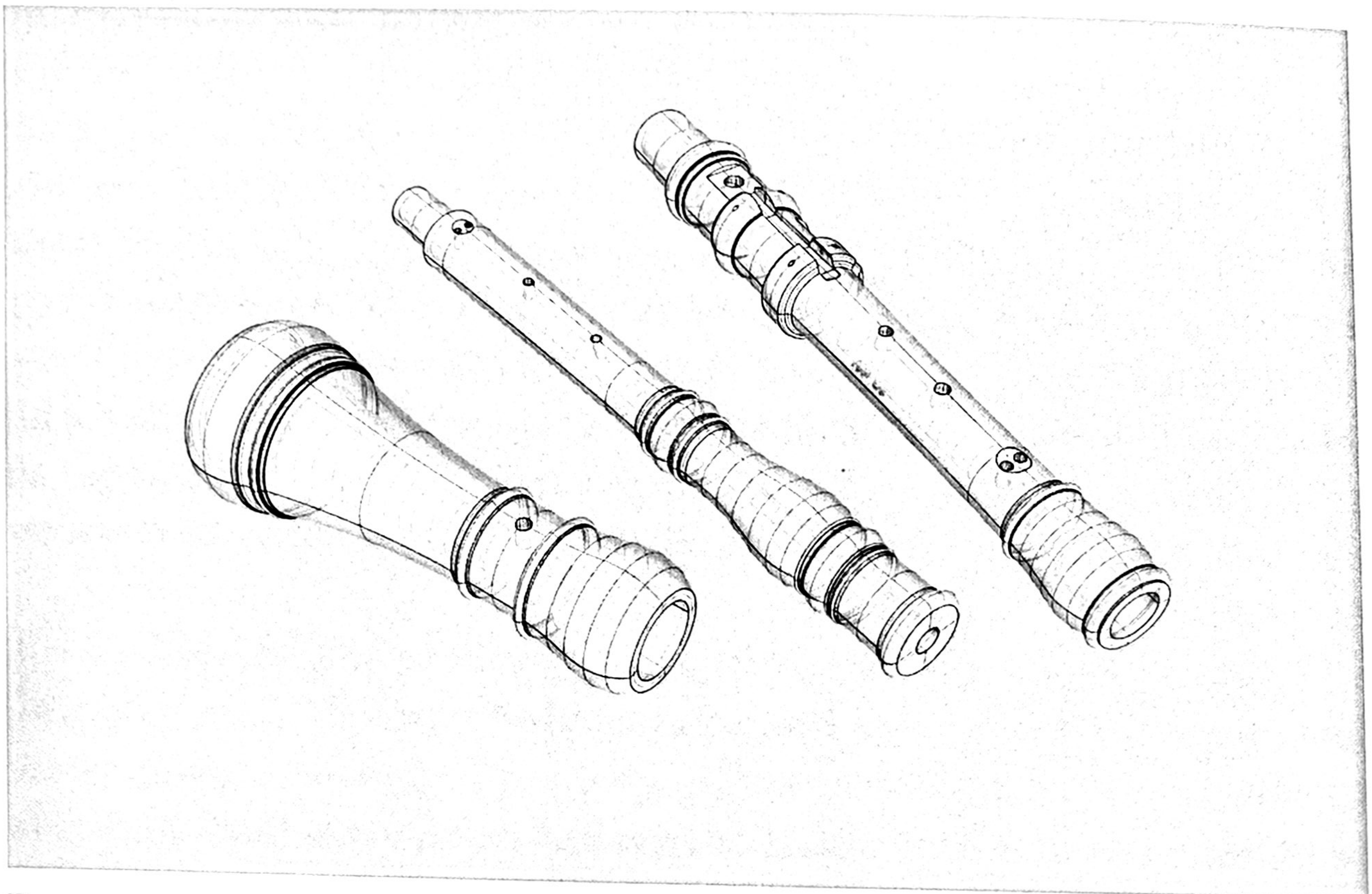


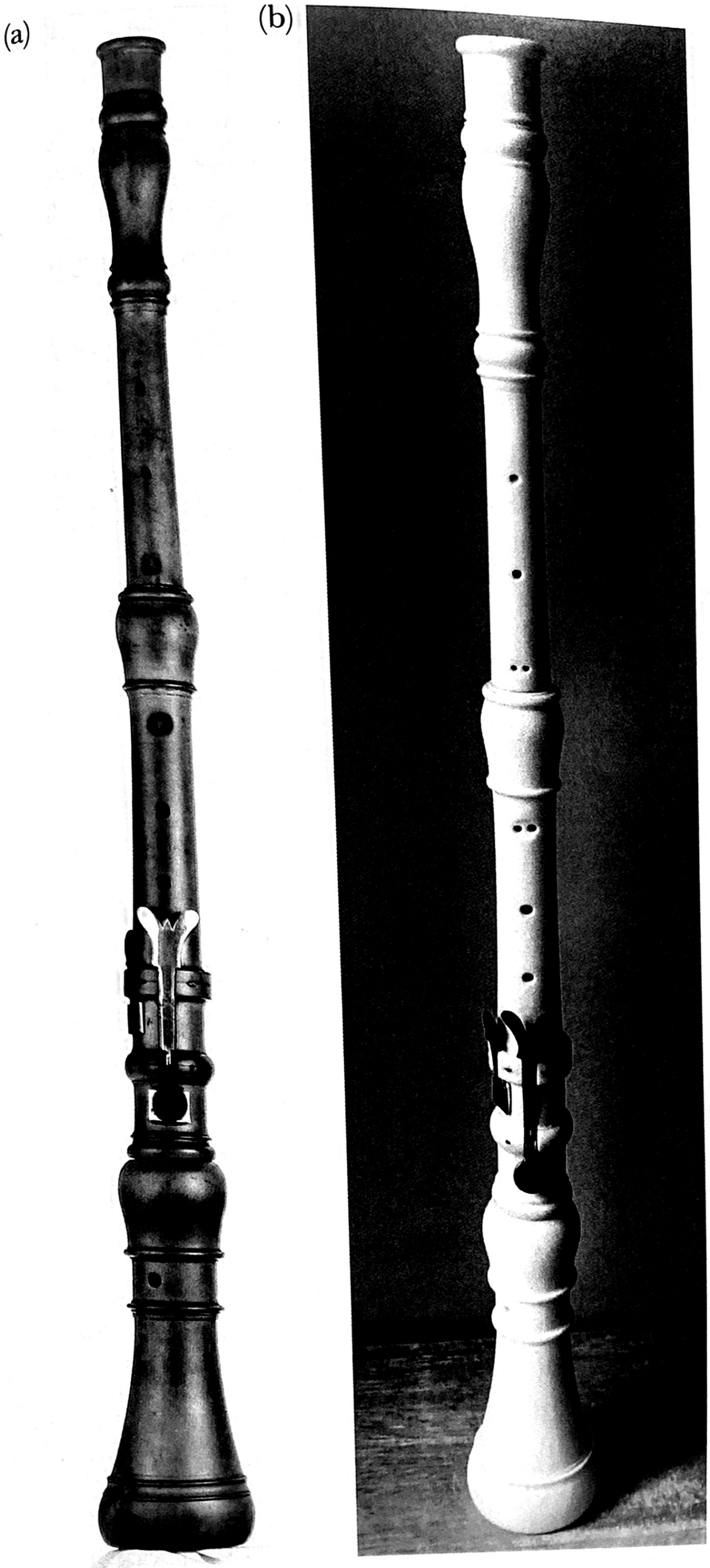
FIGURE 1. 3D-rendering of the I. C. E. Sattler oboe (Leipzig, first half of the eighteenth century). Robert Howe Collection, USA.

structure and density to some woods. A downside is that the polymers react differently to traditional woodworking techniques if modifications are made by hand.

Ideally, a CT (computed tomography) scan of the original artifact is made. Such a CT file can be processed in a computer, but often requires a great deal of work before a printable file can be produced. A practical problem is that these costly CT scanners are not generally found in museums. As a workaround, museums sometimes arrange to use hospitals' CT scanners during night-time hours. In one case, a museum even had to choose whether to assemble or disassemble the 3-joint woodwind instrument (the latter being ideal for printing purposes) before putting it under the scanner, as only one scan could be afforded.

The advantages of this 3D printing approach are many. Developing a prototype and adjusting it is only a matter of adapting the computer file and making a new print. The technology allows the making of new prototypes easily, quickly and at reasonable cost; hardwood timber is preserved, and the 3D-printed musical instrument imitates the wooden one very closely. Eventually it can be used as a professional performance instrument, which is already the case for some instrument types.

Once there is a full measurement or a CT scan, the original instrument



FIGURES 2a–b. (a) I. C. E. Sattler oboe (Leipzig, first half of the eighteenth century). Robert Howe Collection, USA. (b) 3D-printed copy by Ricardo Simian of the same instrument, after a hand-made measurement drawing. Brass keys added by Marcel Ponseele.

can be spared most further measurement. A future possibility is that collections and museums could make or provide 3D-printed copies for testing, or put the scan data online, allowing anyone to print a copy of a museum instrument at home. We can literally transform certain high-resolution scans into printable models with two or three clicks. It does not work every time, it does not apply to every scan format, and you need a good software and computer to pull off the trick (and maybe a little bit of experience with the settings). But we have done it dozens of times for a project regarding fagottini copies last year.

Full CT scans, consisting of many very high resolution "slices" of the object, are enormous: several gigabytes of data. These files can be difficult to process or even to open without suitable software and computer equipment, and even then are difficult to manage. However, a processed 3D model for printing can be just a few megabytes and can be opened and printed with standard open-source software. Large and free databases for ready-to-print 3D models already exist and the same could be done with museum instruments without the need for any technological upgrade.

Case Study: Fourteen Leipzig Bach Oboes (1720–1750)

A recent research project about the "Bach oboe" by the authors resulted in a series of 3D-printed models that served as study objects next to the original instruments.[3] The 3D-printed instruments represent the pitch and playing characteristics and qualities of the original instrument, insofar as the measurement data represent this original. Most of the 3D prints were based on hand-measured drawings with an accuracy of 0.1mm; metal keys were applied to the printed body. In one case, an incomplete measurement could be completed and tested. In another case (involving an ovalized bore), a change of bore measurements from the horizontal plane to the vertical plane was only a few clicks away, whereas in real instrument making new reamers would be costly—if farmed out—and time-consuming. This flexibility saved time and money, as the first attempt resulted in an unplayable oboe. In a few cases, the prints helped to assess instruments that were remote or inaccessible. In case of a Bauer oboe (MIR376 from

3. Stefaan Verdegem & Marcel Ponseele, "Fourteen Leipzig Oboes from the time of Bach," *The Galpin Society Journal* 74 (2021): 70–102.

the Germanisches National Museum in Nuremberg), a CT scan could be obtained and printed out after disassembling the three joints in the scan file.

In addition to the many available materials and models of 3D printers, there are different 3D modeling languages. The most common 3D models for printing are produced with Standard Tessellation Language or Stereo-Lithography (STL), which is generated by defining a surface through many small triangles. The smaller and more numerous the triangles, the more precise and smoother the surface, like pixels on screens. With this language, however, it is difficult to introduce modifications, which in some cases require modifying thousands of tiny individual triangles. On the other hand, a 3D model can also be defined in terms of geometrical shapes and functions. In fact, most 3D modeling software operates in such way; one does not create a sphere by drawing millions of small triangles following a spherical shape, but by simply defining the radius of it. Geometric shapes can be easily modified, but no software will automatically generate them from a complex object like a musical instrument. This task requires some human 3D modeling work, making smart use of the available measurements. This can become completely unfeasible if the geometries are too irregular.

Musical instruments, and particularly historical ones, are difficult objects to reproduce; they may look quite regular but, in reality, they are full of irregularities which may or may not be important. It may be desirable to eliminate a crack when making a copy, but this irregularity will be very laborious to remove if the 3D model was directly extracted from a CT scan, which will certainly copy it in full detail; CT scans were developed to find small cracks and clots in our bodies. Moreover, the musical quality of the instrument can depend on a small detail, such as the irregular undercutting of the holes in a hand-tuned wind instrument, and such small irregularities are very difficult to model as geometric shapes. 3D-modeling software is improving, and some options intermediate between "small triangles" and "geometric shapes" are being developed. But this is not yet an area where a casual user can expect to produce an acceptable outcome, in the sense that easily available photo editing software allows user-friendly manipulation of 2D images.

At the beginning of this article, we asked the philosophical question of whether historical instruments are brought to life when they can be played and thus allowed to vibrate. We may also ask: Are 3D-printed musical instruments alive? Also: Are the 3D models of these same musical instruments alive themselves? And: Is a very intricate and irregular 3D model, which mirrors every crack of a museum oboe, more alive than a model with a smoothed-out surface?

These are not no longer merely philosophical questions, as we can now print real objects using these models, to be played and tested, to be presented to audiences, to make comparisons, and to carry out blind tests. The future of musical-instrument research and instrument development will certainly take place within this evolving field, which increasingly unites traditional methods and new technologies.