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The 3D-Printed Cornett: Reflections on a Decade of Experimentation and Performance

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Abstract

Reflecting on some of the pioneering research that led to the first 3D-printed cornetts (2012–14), this paper describes various ways in which 3D-printed cornetts have since informed our understanding of historical performance practices, before discussing their subsequent use in the author's own professional practice. The latest iterations of the modular 3D-printed cornett at the center of this study demonstrate some opportunities afforded by the technology for innovation in contemporary instrument design, including a version with integrated piezo pickup for performance with live electronics. Finally, the author offers some thoughts on possible future directions for the research, with some consideration of environmental impacts and potential mitigations.

Keywords

3D printing, cornett, historical performance practice, musical instrument design, organology

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Introduction

It is now 10 years since Ricardo Simian and I published our paper in *Early Music* (Savan & Simian, 2014), documenting and reflecting on our first experiences with 3D-printed cornetts. Much has changed in the intervening decade. Although 3D printing was already some 30 years old in 2014, it still seemed to many of us (especially in the early music community) a futuristic, fringe technology. It has now become mainstream, even ubiquitous. CAD software has become more accessible, affordable, and intuitive, while commercial 3D printing has become more widely available with access to a greater range of materials and post-production processes, so the finished products are increasingly refined in feel and appearance.

There are now at least six workshops (of which I am aware) making 3D-printed cornetts on a commercial or semi-commercial basis, and more still are making use of the technology for research and development purposes. Some of these are adding 3D-printed student model instruments as an affordable, entry-level option alongside more expensive, hand-crafted wooden instruments. We can see, therefore, that the technology is not supplanting traditional methods but rather sitting alongside them and supporting the development of new instruments for beginners and professionals alike.

And, while the cornett was an ideal instrument with which to begin experimenting with this technology as a proof of concept, due to its relative simplicity of form and a lack of moving parts, it is hugely exciting to see the technology now applied to a wide variety of instruments with increasingly complex technical demands. Beyond the fascinating examples in this present volume, Simian (2023) offers a further series of case studies that exemplify a variety of recent applications in the field of musical instrument design.

Meanwhile, my own research has taken me in some other directions in recent years, including the use of

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3D-modelling for acoustic simulation of historical performing spaces. Nevertheless, I continue to make use of the insights deriving from my work with 3D-printed instruments, as well as the instruments themselves, in my professional performance practice. In this paper I reflect on some of the findings emerging from my use of 3D-printed cornetts for research in organology and historical performance in the initial phase (to 2014), their subsequent application in my own professional practice (through to 2024), and some thoughts about future opportunities offered by the technology.

Initial Research Phase and Findings, 2012–14

My research began with the 3D modelling of a selection of mouthpieces from the engineering drawings by Graham Nicholson in Tarr (1981). I had these printed in a photopolymer resin at Newcastle University, and although the finish of the material left something to be desired, the models were quite playable, and it was immediately clear they could tell us quite a lot about the originals. Not least, between these three mouthpieces alone, inserted into the same instrument (nominally at A440), the pitch of A4 ranged from 434 Hz to 452 Hz, a discrepancy that called into question many of our assumptions about how we measure the pitch of historic instruments, almost all of which are missing their original mouthpiece.

Following the success of the mouthpiece modelling, the next question was whether the technology might be applied to a complete instrument. Size was a limiting factor at the time, since the printers I had access to back in 2012 had a relatively small printing bed.

So, I designed an instrument in three jointed sections. Its internal dimensions and fingerhole positions were based on the measurements for one of the Christ Church cornetts, published by Julian Drake (1981) – but the bore was straightened out and averaged into a perfectly circular cross section. While I would not therefore claim this to be a "copy" of an original instrument, the model provides an opportunity to understand the essential characteristics of an instrument in terms of its pitch, intonation, and fingering system. I refer to this as an "acoustic model" of the original cornett.

The Christ Church cornetts, housed in the library of Christ Church College, Oxford, were commissioned as a matched pair for the visit of King James I to Oxford in 1605, and have been kept at the college ever since. They are among the most important and best preserved of cornetts to have survived from the period. They have the classic !! makers' mark associated with the Anglo-Venetian Bassano family, and whether these instruments were actually made in London or Venice is impossible to tell. They are built in the classic Venetian style that we see in major instrument collections around the world, but they are pitched rather lower than the majority, and it is likely they were commissioned specifically to align with the pitch of the organ at Christ Church Cathedral.

In 2014 I was granted permission to play the originals under controlled conditions, and under the close supervision of the late Jeremy Montagu and librarian Janet McMullen, to compare them with my 3D-printed acoustic model. Through this direct comparison, I was able to confirm the efficacy of my method in producing a playable instrument that replicated the essential characteristics of the originals.

Some of those characteristics might be described as "eccentric" in comparison with the majority of modern reproduction cornetts in use today. Fortunately, having access to the 3D-printed instrument for several months in advance, I had already anticipated some of the unusual characteristics of the original instruments.

In fact, my first instinct was to "correct" the model to make the instrument align with my expectations coming from the generic modern cornetts that we are more used to playing. Realizing that the notes that use the full sounding length of the instrument seemed to be too low, I took a "virtual hacksaw" to the 3D model, cut 17 mm from the end, and resized the bottom 2 fingerholes to compensate for tuning. And since I was working with a three-piece modular design, I only had to re-print the foot joint.

The result (after several iterations) was an instrument that plays very well using the generic modern fingering system. And, as a cautionary note to those who would use length as a proxy for pitch when talking about extant cornetts, it still plays at A = 440 Hz, even though we have made the instrument nearly 2 cm shorter. But shortening the instrument in this manner would of course have been an easy solution for a maker or player in the seventeenth century, too – so why are the majority of surviving instruments not similarly "corrected"?

I had also already noticed some similar eccentricities in the Bassano instruments of the Accademia Filarmonica in Verona during a research trip in 2013. But, if and when we are afforded the privilege of playing original instruments in museum collections, we can typically only play them for a very short time – not normally long enough to figure out all their idiosyncrasies.

Having access to my 3D-printed model gave me the luxury of time to practice, to experiment, and finally to make some small steps to better understand the historical fingering system of these Venetian instruments. Crucially, it helped me to prepare for the experience of playing original museum instruments when afforded the opportunity to do so, including a visit to Verona in 2014.

Consequently, I was able to present my findings in the *Historic Brass Society Journal* (Savan, 2016), which I do not need to repeat at any length here, but simply to summarize that the historic instruments I studied offer a wider variety of enharmonic fingerings than the majority of "modern" system instruments. In turn, sharp notes tend to be played with simpler, open, fingerings, while flats tend to require more convoluted cross-fingerings. This, in turn, results in a differentiation of tone quality (as well as pitch) between sharps and flats which seems to align with contemporary descriptions of solmization syllables for

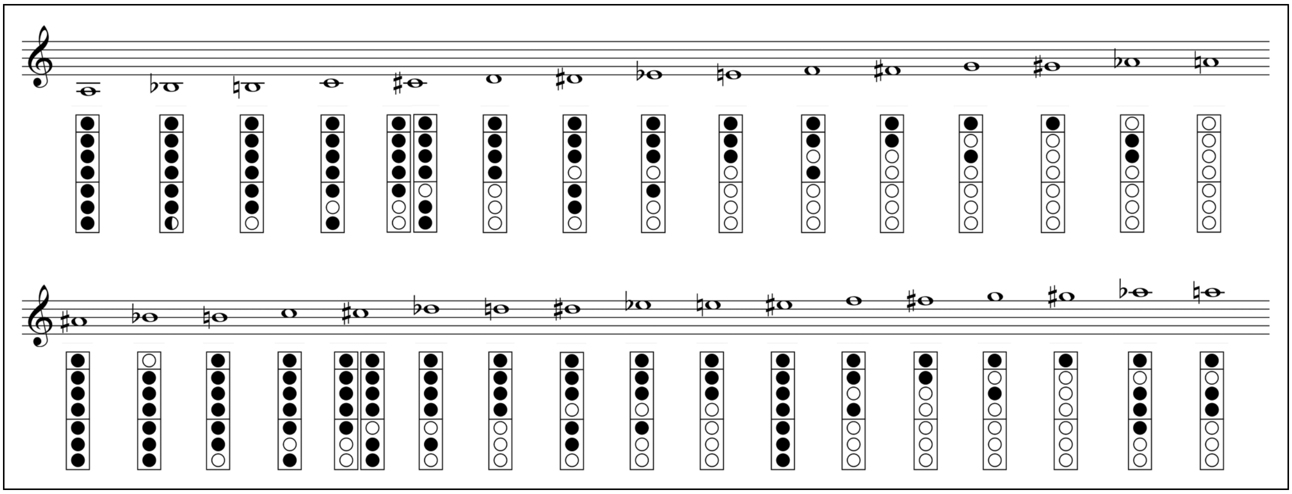

Figure 1. Complete enharmonic fingering scheme for the Christ Church cornetts.

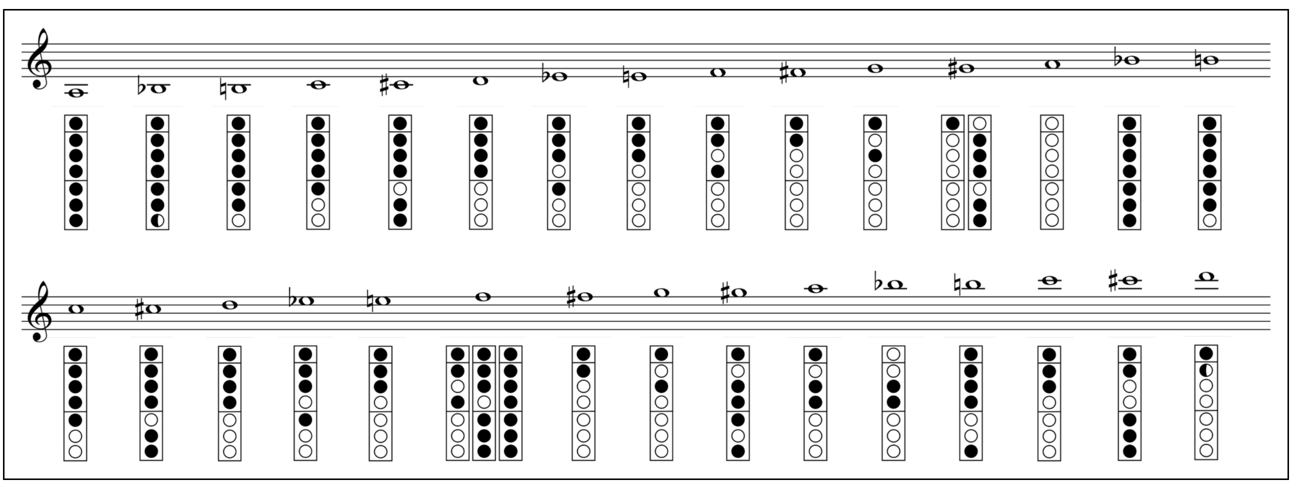

Figure 2. Fingering chart for generic modern cornett. Note the alternate fingerings for G-sharp4 and F5, in which the first given is the fingering found in all original fingering charts, and the second or third are the options more typically used in modern practice.

singers ("mi" as "hard"; "fa" as "soft"). It also facilitates a wider range of transpositions than had previously been acknowledged.

Figure 1 presents a full enharmonic fingering chart for the Christ Church cornetts – also applicable to several of the Bassano instruments in Verona – first printed in my 2016 article, and to which I will refer a little later. The important consideration here is the implication of quarter-comma meantone temperament, a tuning system based on pure major thirds, which results in a difference of 41 cents between sharp and flat enharmonic spellings of what would be ostensibly the same note in equal temperament.

Application in Professional Practice, 2014–2024

My 3D-printed acoustic model of the Christ Church cornetts therefore led to some important insights into the characteristics of a number of original instruments by the Bassanos, with implications for the performance practice of Renaissance music. It has certainly influenced my own practice, informing my understanding of sonority and choice of fingerings when playing my professional handcrafted instruments of wood and leather. I wrote briefly about this when describing the underpinning research processes for the CD production *Venice 1629* with the Gonzaga Band (Savan, 2020).

The principal changes I have adopted in my own playing as a result of this research are applied to two notes in particular where the historical fingering results in a radically different tonal quality from the fingerings generally used in modern practice (see Figure 2). These are F5, where the historical fingering (as found in all original fingering charts) is Thumb, 1, and 3, compared to the generally preferred modern fingering of all holes closed (or sometimes with just hole 3 open); and G-sharp4, where the historical fingering is thumb-only, compared to the much more convoluted

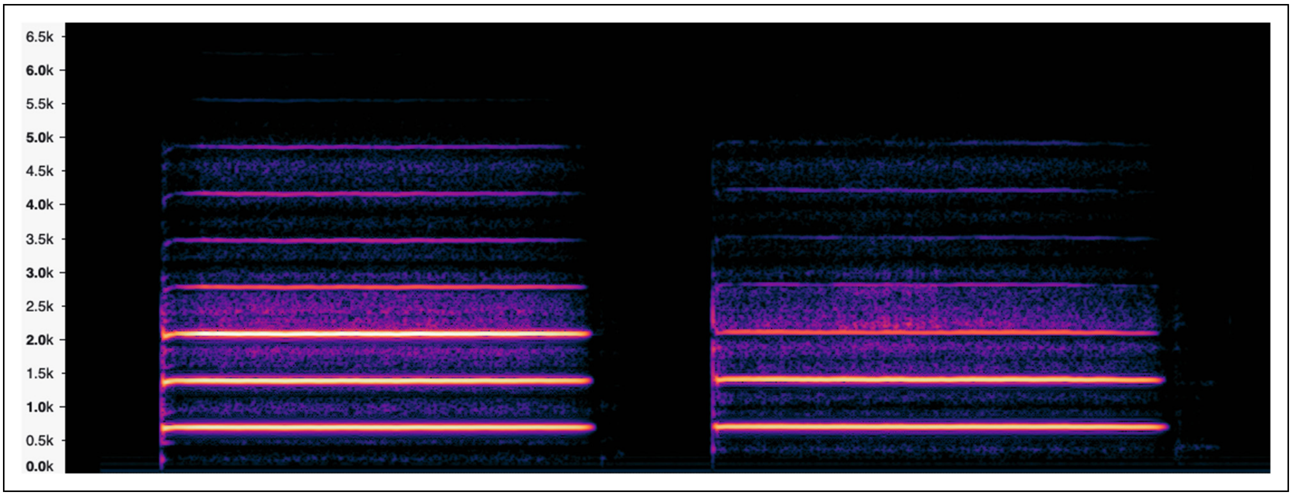

Figure 3. Spectrographic view of F5 played with modern fingering (left) and historical fingering (right).

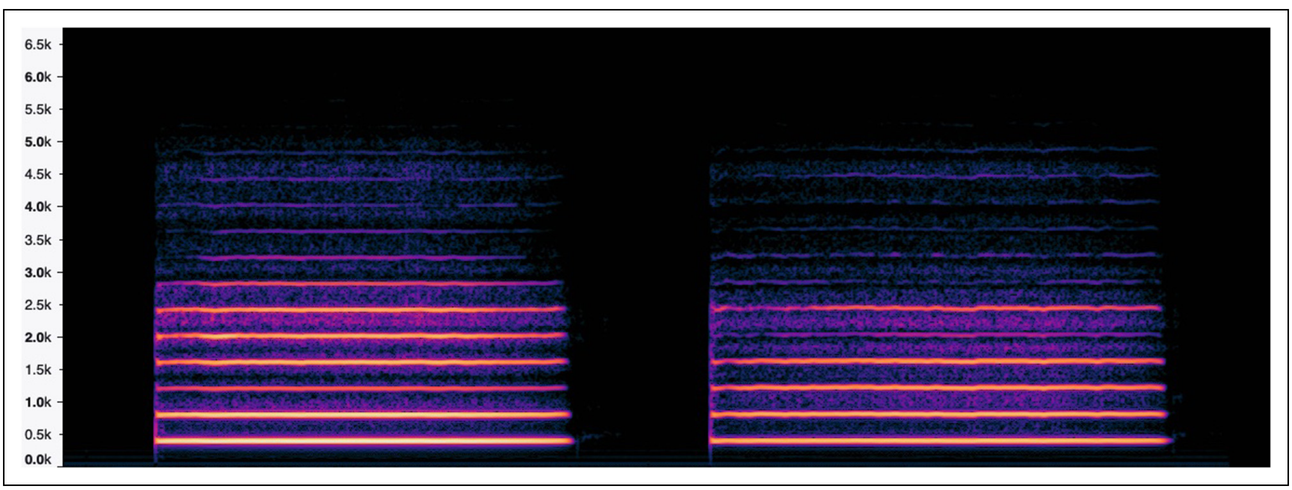

Figure 4. Spectrographic view of G-sharp4 played with historical fingering (left) and modern fingering (right).

modern fingering (necessitated by the way many modern instruments are tuned) of 1, 2, 3, 5, and 6, in which the thumb-hole and hole 4 also need to be shaded somewhat to prevent the pitch from rising too far (to meantone A-flat).

The differences between the modern and historical fingering for F5 are very plain to hear, with the latter sounding much less strident, with a softer tone quality appropriate to that assigned to "fa" by 16th-century theorists (Smith, 2011). Similarly the differences with G-sharp4 are also evident, the historical fingering this time the harder and more strident of the two, in accordance with historical expectations of the tonal quality of "mi."

Figures 3 and 4 demonstrate the tonal contrast between these fingerings in visual form using the spectrographic viewer in Audacity. When playing F5 with the historical fingering it can be seen that the overtones above 2000 Hz are reduced in intensity compared to the modern-fingered equivalent, whereas the overtones above 2000 Hz are considerably reinforced when playing G-sharp4 with historical fingering. These spectrographic examples were recorded using my 3D-printed model with modern foot joint and integrated piezo pickup (as described further, below).

Beyond these insights into historical performance practices, my 3D-printed model with modern foot-joint has become useful in different ways over the past decade, during which I have been able to make various iterations of this instrument available to students, printing "on demand" since 2014. In 2020, I worked with instrument designer Joe Wright to make some ergonomic improvements, including a curved, jointed mid-section (a form not easily achievable using traditional methods), as well as some refinements of tuning, during the extended periods of Covid "lock-down" (Figure 5). These improvements derived from a better understanding of the material properties of SLS nylon, which remains tough and durable even when printed with relatively thin walls, so it made sense to remove the cumbersome reinforcement around the tenon joints and the mouthpiece receiver that I

Figure 5. JS440 model 3D-printed cornett with curved mid-joint, rendered by Joe Wright.

had initially imagined would be necessary, as they would be if turning similar pieces from wood. The wall thickness at the joints in this revised model are a little over 2 mm but remain very strong.

An added benefit of this ergonomic redesign is that the headjoint can now be "nested" within the footjoint and the two pieces printed simultaneously during the manufacturing process. This saves space within the printing chamber and consequently reduces the production cost of the instrument. In the hope this might be useful information to future designers in the field, I note that orientation of the CAD model within the print chamber is also an important factor in the consistency of production. I discovered through an extended process of trial and error that hollow, elongated conical parts are best printed in vertical orientation to reduce the potential of the model warping as the material cools in the machine.

One advantage of a three-piece, jointed instrument is that its pitch is much more easily adjustable than with traditional, one-piece instruments. I have been able to take advantage of this in professional performing situations, including the performance of contemporary music by Martyn Harry, whose movement "Court of Augmentations" from his suite *At His Majestys Pleasure*, commissioned by His Majestys Sagbutts & Cornetts in 2011, calls for cornetts to be tuned a quarter-tone apart. It is also useful when required to perform in unusual historical pitches, for instance if required to play Gluck's *Orfeo* at "classical pitch", A = 430 Hz.

For performing at other pitches at a greater remove from A = 440, rescaling the model is an option. For a recording of music by Gioseffo Guami in 2015, I needed an alto cornett (one tone lower than a standard treble cornett) in A = 466 (which we might also think of as a treble cornett in A = 415). So, I resized my original 3D model to 106% (the scale derived from dividing the existing pitch of 440 by the desired pitch of 415) and printed a larger instrument that worked well with just a little hand tuning of the fingerholes. This cornett may be heard on the album, *La Luchesina* (His Majestys Sagbutts & Cornetts, 2015). It should be noted that rescaling an instrument is a very different proposition to the simple shortening of overall length (as I did for comparative purposes with the Christ Church model), since this also involves a proportional repositioning and resizing of the fingerholes. The potential for rescaling and developing cornetts to fit multiple pitch standards – or indeed to produce bespoke instruments that fit between the 415–440–466 matrix of historical pitch approximations – is one of the key advantages of the technology. Indeed, since 2014, Ricardo Simian was quickly able to build a successful micro-enterprise based on this principle: See https://cornetti.3dmusicinstruments.com/ for examples of the wide range of standard and bespoke pitch options currently available.

Another application of the technology that has proven invaluable in my professional practice is the production of mouthpieces. This issue has come to the fore especially since the Brexit vote of 2016 and the knock-on implications for UK-based musicians of travelling with CITES-protected materials. Since 2003, I had been using a mouthpiece of antique ivory, which was in turn a recycled billiard ball from the nineteenth century. Unfortunately, however, I had no paperwork to prove its antique origins, and under new regulations from 2021 onwards, I would no longer be legally permitted to take it in or out of the UK – clearly a significant problem for a travelling musician!

Anticipating the likelihood that I would eventually need to replace this favorite mouthpiece, I had already learned to make mouthpieces from horn and wood on a small model-maker's lathe. I achieved some success with this, producing mouthpieces that colleagues and students seemed to like, but no matter how close I managed to get by traditional methods of hand and eye, I was never quite able to replicate the feel and sound of my ivory mouthpiece. For any brass player, the choice of mouthpiece is very personal, and players will attest to the effect of the tiniest change in the geometry of a mouthpiece to the playing experience. For a mouthpiece as small as that of a Renaissance cornett, the tolerances involved are very fine indeed. So, I turned to CAD modelling and 3D printing and the promise of accuracy of replication to within ± 0.05 mm for certain materials. I was careful to avoid commercial photopolymer resins for which, despite their accuracy, the long-term safety of skin contact is not yet assured, and turned instead to metals that can be cast in a 3D-printed mold using the (traditional) lost wax method. This has yielded very consistent results, but to compensate for shrinkage in the casting process the CAD models need to be resized to 101%. I have experimented with iterations in polished brass and bronze, and my preferred daily mouthpiece since 2020 is a near-perfect replica of my ivory original in sterling silver.

Most recently, I have taken further advantage of the modular nature of my 3D-printed cornett, incorporating a small hole printed into the head joint to receive a threaded insert for a piezo pickup (PiezoBarrel®), enabling the cornett to truly enter the world of contemporary music as an electro-acoustic instrument. The key advantage of incorporating a pickup within the bore is to minimize the phenomenon of a feedback loop between the microphone and loudspeakers in performance. This forms part of an artistic research project exploring the possibilities for a single-line instrument to perform polyphonically in real time, in repertoire ranging from Renaissance canons to new commissions by living composers. One of these commissions, Benjamin Tassie's 2023 composition *Glass Coloured* for cornett and live electronics, explores the microtonal tunings implicit in the enharmonic distinctions of the Christ Church fingering chart (Figure 1) in combination with the latest spectral processing capabilities in Ableton Live 11 (using real-time fast Fourier transform processes), hence offering a fusion of old and new approaches to cornett performance practice. This can be heard on the album *The Polyphonic Cornett* (Savan & Dooley, 2024), together with a set of Renaissance canons by Johann Walter, contemporary canons by Timothy Roberts, and a further commission, *Palimpsest*, by Martin Harry.

Future Directions

3D-printing technology has allowed for continued experimentation that is much faster and more affordable than production of new instruments by traditional methods. These factors enable, and even encourage, risk taking in the design process. I would not have chanced drilling a hole for a piezo pickup in an expensive wooden instrument, for instance, and certainly would not have considered doing this in multiple iterations to find the optimal acoustical position for the pickup, as I was able to do with 3D printing. But as I inevitably discard some of the less successful results of these experiments, I am increasingly aware that this activity has an environmental cost that has not yet been adequately quantified.

As an additive manufacturing (AM) process, 3D-printing is arguably less wasteful and therefore more sustainable than traditional, subtractive processes. However, the environmental impacts of these technologies are still not well understood (surveys by Khosravani & Reinicke, 2020; Nyika et al., 2021; Shuaib et al., 2021, highlight some of the issues and gaps in current understanding). Ricardo Simian touches on the question of sustainability in a recent paper, calling it "a contested topic in AM, to say the least," but proposing it as an important criterion for evaluating the efficacy of AM in different use cases (Simian, 2024). Selective laser sintering (SLS) (the technology many of us are using in production of instruments) involves the fusion of PA12 nylon powders into 3D objects, so we are essentially dealing with industrially produced microplastics as our raw materials, within an energy-intensive manufacturing process. It is therefore incumbent on us to give some consideration to the potential environmental consequences of the technology if we are to use it responsibly and ethically in our future research endeavors. Indeed, such environmental considerations are increasingly recognized as integral to responsible research and innovation obligations and form part of the PAS440 Framework (British Standards Institution, 2020).

One way in which we might reduce our reliance on the physical printing of instruments for research purposes is to develop further the potential for parametric modelling. This is something Ricardo Simian and I had discussed back in 2014 as a possible future development, but it seemed too speculative at the time to warrant inclusion in our article. However, Simian has since demonstrated a most elegant and promising solution to the question of parametric control of CAD cornett models at the ZinkNet conference in Geneva in September 2024. If this development can be combined with the virtual acoustic modelling of impedance values in wind instruments now possible via the OpenWinD software developed by the Inria Makutu research team in Bordeaux (https://openwind.inria.fr; Chabassier et al., 2020), then we have a basis for iterative instrument design and testing of both historical models and new innovations while minimizing the need to print physical instruments until much later in the development process.

In essence, such virtual acoustic modelling of instruments would involve processes analogous to those deployed in acoustic modelling of historical performing spaces, currently a burgeoning field in the study of cultural heritage (exemplified by Cook et al., 2023), in which I am currently engaged as Principal Investigator for "Aural Histories: Coventry *c.*1451–1642," a multidisciplinary research project funded by the UK Arts and Humanities Research Council. In this project, the acoustic modelling software Odeon is used to accurately predict the acoustic performance of a virtually reconstructed historical space, based on a combination of its geometry (via a CAD model) and sound absorption coefficients of its surface materials and furnishings. Ultimately, to situate our virtual instruments within such virtual performing spaces would be to close the circle and enable us to deepen our understanding of the interaction between historical instruments and the acoustic environments in which they were designed to be heard.

Another development that is likely to significantly improve our understanding of historical cornetts is the availability of computer tomography (CT) scan data for an increasing number of original instruments. This is currently being driven by Lambert Colson and colleagues at the ZinkNet project in Geneva, the essential aim of which is to connect historical sources of cornett repertoire with surviving instruments. While the scans will no doubt reveal intricate details and idiosyncrasies of individual instruments, I believe the main value of additional CT scan data is the potential to conduct long range surveys of instruments from a particular workshop or time period, so that we can understand more clearly the overall principles and practical philosophies of instrument construction.

Physical models will of course still have a role to play in triangulating the measurement data derived from historical instruments and the predictions of the simulation software. They will also continue to yield rich research insights until software such as OpenWindD is able to account for the full acoustic properties of an instrument including threshold pressures and transients, for instance, aspects that directly affect not just the sound but the "feel" of an instrument, its response, and its character of articulation.

In 2014 Simian and I referred to Bruce Haynes's idea of instruments in museum collections as being "like a dictionary one can go back to, and if you bring new questions they will give you answers you never dreamed of" (Haynes, 2007, p.162). We suggested that 3D printing of historical instruments might enable the realization of such a "dictionary"; but in the longer term it may be that the more sustainable – and perhaps ultimately more useful – dictionary will be a virtual one, that we can interrogate in different ways without the need for physical models until we are ready to test our musical hypotheses in performance.

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Declaration of Conflicting Interests

The author declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The author declares that the 3D-printed cornetts which form the focus of this study are offered for sale via his personal website, www.jamiesavan.com.

Ethical Approval

This research did not require ethics committee or IRB approval. This research did not involve the use of personal data, fieldwork, or experiments involving human or animal participants, or work with children, vulnerable individuals, or clinical populations.

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