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Digitally Manufacturing Fagottini at the Schola Cantorum Basiliensis: Reconstructing Historical Instruments According to Contemporary Requirements

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Abstract

The research on fagottini, carried out in Basel between 2017 and 2023, provided the basis for reconstructions of 18th- and 19th-century small bassoons using digital technologies, including 3D–CT scanning and additive manufacturing. This interdisciplinary initiative combined historical expertise with industrial innovation to produce replicas of these fragile instruments, making a significant contribution to the fields of historical musicology, conservation, and pedagogy. This paper discusses the methods and results of the project, emphasizing their implications for the conservation, analysis, and construction of historical woodwind instruments. The project addressed the challenge of maintaining the relevance of reconstructed instruments beyond the research phase by implementing a pedagogical framework at the Schola Cantorum Basiliensis, a specialist early music institution located in Basel, Switzerland. These instruments are now actively used to support three key objectives: promoting historical performance practice, enhancing pedagogical strategies, and enabling further musicological research. By integrating the replicas into these contexts, the project ensures the continued use of these instruments while fostering a deeper understanding of historical practices. The results highlight the transformative potential of digital technologies in historical musicology, bridging traditional craftsmanship and modern tools. The use of 3D-printed replicas in education and performance demonstrates their value in making historical practices more accessible while preserving the original instruments. Ultimately, the fagottino project exemplifies how collaborations between researchers, industrial innovators, and specialized institutions can make lasting contributions to scholarship and pedagogy. It sets a precedent for the integration of technological advances into historical research and reaffirms the critical role of reconstruction in preserving and revitalizing musical heritage for contemporary use.

Keywords

Additive manufacturing in musicology, CT scanning woodwind instruments, cultural heritage, digital humanities in music, digital models of historical instruments, early music pedagogy, historical instrument reconstruction, pedagogy and performance practice, playable replicas of early instruments, 3D printing musical instruments

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Introduction

The application of advanced technological methods, such as computed tomography (CT) scanning and three-dimensional (3D) printing, has increasingly surpassed their original disciplines to make significant contributions to unforeseen fields such as musicology and historical research. Specifically, CT scanning and 3D printing have demonstrated their

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Data Availability Statement included at the end of the article potential to transform the study of musical instruments. In the case of museums with instrument collections as well as major institutions, there is a tendency showing a significant change over the past several decades. Initially focused on preserving artifacts as static displays or repositories, these institutions now highlight research, education, and digital outreach. Museums and research facilities increasingly integrate CT scanning and 3D printing into their practices, signaling a broader shift toward innovation in the study and dissemination of historical collections, as evidenced by numerous institutional publications (Darmstädter et al., 2011).

Digitalizing historical artifacts involves significant upfront costs and technical challenges, yet offers long-term benefits. By reducing the need for physical handling of delicate items, digital reproductions contribute to the preservation of original materials. Moreover, digital models and printed replicas expand access to collections, enabling researchers and teachers from all over the world to study and interact with artifacts in ways previously unimaginable. Several institutions, such as the Germanisches Nationalmuseum in Nuremberg working under the project MUSICES in 2014–2017 (Bär & Fuchs, 2018) and more recently the Royal College of Music in London (3D Printed Musical Instruments, n.d.), have adopted CT scanning for archival and research purposes, demonstrating the growing acceptance of these technologies. Another illustrative example is the Museu de la Música in Barcelona, which in 2023 has scanned and reproduced six historical instruments, including an 18th-century traverso flute and a 17th-century Catalan Xeremia. These replicas, which visitors can handle and play, exemplify the balance between preserving original artifacts and engaging the public (Ruiz & Guasteví, 2023).

Along with museums, major research and teaching institutions have incorporated these new technologies into their research projects. This paper focuses on the innovative use of these techniques to study and reconstruct historical woodwind instruments, thereby improving the conservation, analysis, and accessibility of these fragile artifacts. Specifically, the research on fagottini carried out in Basel between 2017 and 2023 provided the basis for the reconstruction of 18th- and 19th-century small bassoons using digital technologies, including 3D–CT scanning and additive manufacturing. The paper discusses some of the findings of this research project, including how the results can be used in pedagogy and historical performance practice. These projects highlight the intersection of digital humanities and traditional craftsmanship, paving the way for new approaches to the analysis and reproduction of historical instruments.

Fagottini at the Schola Cantorum Basiliensis

The fagottino projects represent a series of groundbreaking research initiatives carried out at the Schola Cantorum Basiliensis, FHNW (University of Applied Sciences and Arts Northwestern Switzerland) by a team of musicologists and performer-researchers.[1] These projects, funded by the Swiss National Science Foundation (SNSF), comprise three key studies: "Fagottini and Tenoroons: Small Forgotten Giants" (2017–2019), "Out of the Bass Register" (2020–2023), and "Neue alte Klangkörper / 3D-Fagottini: A Multi-Method Approach to Reconstructing Two Original Eighteenth-Century Fagottini with 3D–CT Modelling" (2020). Together, they advance our understanding of historical fagottini and tenoroons, with a strong emphasis on the application of innovative 3D technologies in the study and reconstruction of these rare instruments.

The projects explored the organological and musicological aspects of smaller bassoons, commonly known as fagottino and tenoroon, of the 18th and 19th centuries, addressing their historical use in orchestral, chamber, operatic, and sacred music contexts, as well as their pedagogical role. This research highlights the multifunctionality of fagottini and tenoroons in musical and cultural life before their decline in the 20th century. A significant aspect of these projects is the integration of cutting-edge 3D scanning and printing technologies, particularly as explored in the 2020 project on 3D–CT modeling. This initiative was the first systematic attempt to apply 3D technologies to the study of fagottini. Using 3D scanning, the team produced highly detailed digital models of original 18th-century instruments, capturing subtle deformations and structural nuances that are otherwise undetectable through traditional methods.

The methodologies and objectives of these projects represent a bridge between contemporary digital humanities methodologies and the traditional, yet labor-intensive, craft of manual research, which is characteristic of historical instrument-making practices. Throughout the survey process, researchers visited both public and private wind instrument collections where they measured, documented, and, when possible, played individual instruments. To support comparative analysis, they supplemented their observations with existing documentation and earlier research. They further refined their methods through close collaboration with industry professionals and traditional craftsmen. In developing the fagottini, the team worked with Ricardo Simian on the modeling and 3D printing of the instruments, consulted with CT scanning specialists Sebastian Kirsch and Niko Plath, and drew on the expertise of instrument-maker Vincenzo Onida.

The research team compiled a catalog listing all fagottini and tenoroons recorded during the survey (Agrell et al., 2025). They identified approximately 120 instruments and selected six for detailed examination based on historical significance and physical condition. To support this analysis, the team conducted 3D scans of the selected fagottini at the Fraunhofer Development Centre for X-ray Technology (EZRT) in Fürth, using a high-resolution CT system originally developed for industrial materials testing. Owing to the fragile condition of many instruments, direct playability was not always possible. To enable acoustic testing, the team created reconstructions and copies of the selected instruments. These reproductions were made using both traditional techniques and 3D printing. In the traditional approach, craftsmen-built replicas by hand, working from adapted measurements obtained through the 3D–CT scans. These data served as the basis for fabricating reamers and other tools required to shape the instruments using historical methods. By contrast, digital fabrication enabled researchers to efficiently produce precise and reproducible copies, with a high degree of control over structural modifications.

Additive Manufacturing Methods and Model Preparation

In the reconstruction process, the team opted to preprocess the 3D models before initiating the 3D-printing phase. This method, as opposed to directly transferring 3D scan data to the printer, allowed for the exploration of multiple reconstruction options. For instance, two distinct replicas were created: an exact copy of the original instrument and a modified version that corrected for the deformations and imperfections that had developed in the wood over two centuries. Once the dataset was prepared, instruments could be reliably reprinted in materials of varying densities using suitable 3D-printing facilities. The selective laser sintering (SLS) technology used in this project creates objects by fusing layers of the chosen material, such as SLS-PA12 nylon, a technology often discussed in the manufacture of printed wind instruments (Damodaran et al., 2021). This method uses a laser to fuse layers of material, such as nylon, into a cohesive structure that mimics the density and texture of wood. This integrated approach, ranging from model processing to SLS printing, effectively minimizes the imprecision inherent in traditional handcrafting techniques and the inconsistencies of organic materials.

The application of 3D-printing technologies enabled the creation of synthetic prototypes of several small-sized bassoons, shown in Figure 1, which were followed by conventionally handcrafted models in wood. This dual-method approach facilitated a detailed comparison of the organological, acoustical, and musical qualities of the instruments. Furthermore, the use of 3D modeling offered unprecedented opportunities to study bore deformation, material shrinkage, and other age-related changes in the instruments. The ability to replicate both the original, deformed bores and the corrected, idealized versions provided unique insights into the instruments' acoustical performance and historical faithfulness.

Despite the clear advantages of 3D printing, researchers have raised concerns about potentially losing the intangible qualities inherent in handcrafted instruments and organic materials. To explore this issue, the research team partnered with traditional instrument-makers, including Onida (2025), to produce handmade replicas alongside 3D-printed versions. The team then used both types of replicas in performance research and shared the outcomes with the public through symposiums, live concerts, video recordings, and academic publications.

Selecting Fagottini for Research Analysis

The fagottino is a small wind instrument belonging to the bassoon family. The term *fagottino* refers to all types of transposing small bassoons, as well as to models that sound an octave higher than the bassoon. Instruments pitched a fifth or fourth higher can also be referred to as tenoroons in G or F. While modern musicians and educators may associate the term with a simplified version of the bassoon developed for children in the late 20th century, this contemporary pedagogical tool is distinct from the historical fagottino. This instrument, which was in active use until its decline in the early 20th century, was a fully functional performing instrument, not merely a simplified version designed for beginners. Historically, the fagottino served as a legitimate variant within the bassoon family, much like the E-flat clarinet, piccolo trumpet, or soprano saxophone in their respective families. These smaller instruments offered unique tonal colors, historical contexts, and expanded orchestration possibilities.

As Domínguez (2024) observes, the fagottino featured in a range of musical contexts such as chamber, orchestral, operatic, and sacred, fulfilling functions similar to those of the full-sized bassoon while offering a distinct timbre and set of capabilities. Composers did not treat the fagottino merely as a pedagogical tool; rather, they integrated it as an independent voice in ensemble settings. In sacred and theatrical works, such as Mattheson's *Das Größte Kind* and Porpora's opera *Siface*, the fagottino appears in specific arias to evoke particular sonorities or support tenor lines, demonstrating its purposeful inclusion in 18th-century orchestration. Understanding the historical role of the instrument sheds light not only on its unique musical identity but also on its significance within broader trends in wind instrument development and orchestration practices. By the 19th century, performers increasingly turned to tenoroons in F for their versatility, often substituting them for the English horn in ensembles lacking a dedicated player. These evolving uses reflect the continuing musical relevance of smaller bassoon variants and their nuanced contributions across historical periods.

The construction of historical fagottini, like other bassoons of the period, varied in size, key configuration, and materials, with examples ranging from four to eleven keys and made from woods such as boxwood, maple, and tropical hardwoods. Their smaller size and specialized design allowed them to occupy a unique place in the bassoon repertoire, complementing the tonal range of larger bassoons and enriching the sonic palette available to composers and performers. The morphological changes observed in the fagottino during the study period are closely linked to concurrent transformations in the bassoon. Investigating instruments of reduced size provides valuable insights. As discussed by Domínguez (2025), key builders of the era produced smaller models, allowing for a focused study of their construction techniques.

Figure 1. From left to right: 3D-printed copies of FT30 Scherer fagottino, FT6 anonymous tenoroon in G, FT42 Savary tenoroon in F. Photo by the author.

The research team selected a group of instruments, listed in Table 1, to capture key features and variations representative of the period and to address the specific challenges associated with each model. The selected instruments have unique characteristics and offer a wide range of materials and design features. Most of these instruments are

Table 1. Instruments selected for the research project.

Instrument	Current location
FT 6. Anonymous, 8-key tenoroon, Vienna, ca. 1815	Private Swiss collection
FT30. Johannes & Georg H. Scherer, 5-key fagottino, Butzbach, ca. 1760–1778	Museum für Gestaltung, Zürich
FT40. Anonymous, 4-key fagottino, anonymous, Germany, ca. 1750–1790	Private Swiss collection
FT42. Jean-Nicholas Savary Jeune, 11-key tenoroon, Paris, ca. 1840	Private Swiss collection
FT44. Johannes & Georg H. Scherer, 4-key fagottino, Butzbach, 1760–1770	Museum für Musikinstrumente der Universität Leipzig
FT50. Heinrich Grenser, 6-key fagottino, Dresden, ca. 1806–1813	Musikinstrumenten Museum, Staatliches Institut für Musikforschung, Berlin

made of maple (FT40, FT42, FT44, FT50), while others use denser materials such as the FT6 in rosewood or the FT30 in boxwood. The number of keys also varies considerably, from four on some of the oldest instruments to the 11-key Savary FT42, which presents unique challenges in terms of mechanical and acoustic replication. In addition, although most wind instruments of the period have brass keys, the FT50, which has ivory keys, was chosen to provide as much material diversity as possible. The selection of instruments also includes models with different transposition. Fagottini such as the FT30, FT40, FT44, FT44, and FT50 are tuned an octave higher than the standard bassoon, while the FT6 tenoroon is tuned a fifth higher in G and the FT42 in F, sounding a fourth higher than the standard bassoon. Furthermore, as can be seen in Table 1, the selection includes instruments made in different geographical styles, including German, French, and Viennese traditions. This diversity represents a small but significant cross-section of the instrument-making schools of the period and provides a solid basis for the analysis of historical fagottini. The fagottino project team archived photographs, exact measurements, and additional details of these instruments as specific datasets in the fagottino project repository of DaSCH – Swiss National Data and Service Centre for the Humanities (Agrell et al., 2023).

Methods and Challenges of 3D–CT Scanning

CT scanning, a technology widely employed in medical and industrial applications, works by capturing a series of X-ray images from different angles and reconstructing them into a 3D representation of an object's internal and external structures. In industrial CT scanning, a rotating X-ray source projects beams through the object, which are detected and mathematically reconstructed into voxel-based models. Different materials absorb X-rays at different rates; a phenomenon known as attenuation, which allows high-density materials such as metals to appear more opaque in scans. Challenges arise when scanning composite objects such as woodwind instruments that include both metal and wood, due to their differing X-ray absorption properties. These issues manifest as imaging artifacts, such as streaks or beam hardening, and must be mitigated through calibration and digital post-processing. This method's ability to produce high-resolution, non-invasive scans makes it particularly suited to the study of delicate and irreplaceable objects, including historical woodwind instruments. By capturing the internal geometry and structural details of such instruments without subjecting them to physical stress, CT scanning mitigates the risks associated with handling fragile items, thus preserving them for future generations. It was discussed (Howe et al., 2014) that the data obtained from CT scans enable researchers to examine the structural and acoustic properties of historical instruments in unprecedented detail. This information, which includes bore dimensions, wall thickness, and hidden internal features, can then be processed to generate precise 3D models. Such models serve as a foundation for further analysis, modification, or reproduction using 3D-printing technologies. These reconstructions offer an avenue for experimental research into the performance characteristics of historical instruments while safeguarding the original pieces within archival collections. In this light, the Germanisches Nationalmuseum in Nuremberg pioneered the establishment of guidelines and standardized procedures for 3D scanning of woodwind instruments, which was followed in the fagottino scans (Bär & Fuchs, 2018).

This phase of the ambitious fagottino research project aimed to produce playable, 3D-printed replicas of historical instruments. The primary method employed involved the creation of digital CAD models derived from 3D imaging using X-ray CT. X-ray CT scanning serves as a powerful tool for capturing intricate structural details. The CT scanning of the fagottini was carried out at the Fraunhofer Development Centre for X-ray Technology (EZRT) in Fürth, Bavaria. Utilizing a high-resolution CT system originally developed for industrial material testing, the process achieved a spatial resolution of 96 μm, enabling dimensional measurements with an accuracy of up to 0.1 mm.

For the fagottino project, only the 3D-scanned instruments were printed; however, in the scope of the project, the team collected manual measurements of instruments that were examined in different museums and private collections. Traditional luthier techniques, such as those described by the research team (Dominguez et al., 2023), were applied to measure approximately 60 additional instruments beyond the six that were scanned, providing a broader comparative dataset. While manual measurements are prone to slight human error, they remain a viable option when digital methods are inaccessible. In addition, 3D scanning enables the detailed study of construction techniques and historical modifications that would otherwise be impossible to observe.

Tomographic scanners must be calibrated according to the specific materials being imaged. When materials with significantly different X-ray absorption properties, such as wood and metal, are scanned simultaneously, image artifacts (e.g., beam hardening, streaking) can occur. These artifacts result from the scanner's inability to optimize imaging parameters for both materials simultaneously, which can compromise the accuracy of the resulting 3D model. To mitigate this issue, the research team removed as many metal components and keys as possible from the fagottini so that each material could be scanned separately. However, certain components, such as key saddles or rings, could not be separated from the wood due to their integral nature or the fragility of the instruments, many of which came from museum collections. As a result, some of the scans suffered from interference, requiring extensive post-processing of the affected files. These same problems have been described by Lehmann and Mannes (2012, p. 39), who in their study of wood by radiation technique describe similar problems with the scan of the wing joint of a Savary bassoon that included the metal keys. After acquisition, the raw scan data were exported in DICOM format and imported into segmentation software to isolate the air columns and bore structures. These segmentations were used to generate stereolithography (STL) meshes, which were cleaned and optimized. In cases where the instruments were too degraded or ovalized, manual corrections were applied based on the largest internal bore diameter across each cross-section. The finalized STL files were then prepared for additive manufacturing using slicing software tailored to the SLS printer, which used PA12 nylon as the material.

The 3D tomographic scans of historical musical instruments FT40, FT44, FT6, FT42, FT30, and FT50 have provided invaluable insights into their construction techniques, material properties, and historical modifications. These scans not only enhance our understanding of the instruments but also underscore both the opportunities and the challenges associated with applying advanced imaging technologies to the study of historical musical instruments. The scan of the bell in the FT40 fagottino provided a relatively clean scan due to the absence of a metal crown, which is a common source of interference. However, metal staples in the butt joint and long joint added significant noise to the scans, as these components could not be removed. Despite these limitations, the successful removal and separate scanning of the butt cork allowed accurate measurements of its angles and dimensions, providing a detailed understanding of its construction. In contrast, the FT44, a Scherer instrument, demonstrated the effect of a metal crown on scan quality. The bell chamber, characterized by its round shape, showed clear construction details despite the interference of the crown. The image revealed fine details of the wood grain, providing insight into the craftsmanship and material properties. The tomography proved particularly effective in measuring the tone hole angles with unparalleled precision that cannot be achieved by manual methods. For example, the tone holes in the wing joint were clearly distinguishable, and the undercut in the long joint was visible, although metal artifacts posed challenges that required post-processing. The FT6 tenoroon, built in the Viennese style, revealed the use of a harder wood in its construction. The characteristic Viennese cut-outs for the keys are clearly visible in the scan, as is the density of the material. The bore of the instrument was particularly round, with almost no deformation, as confirmed by the cross-sectional image, demonstrating its structural integrity and the precision of its design.

The FT42, attributed to Savary Jeune, offered a detailed view of the bell construction, reflecting the craftsmanship typical of this maker. The bell construction, as shown in Figure 2, reveals how the end of the bell was made separately and then attached to the rest of this part of the instrument. This allows the conicity to be reversed and the diameter to be open for more sound projection. This craftsmanship would be impossible to detect by examining the instrument without the scan. The images in Figure 2 are part of the raw data of the datasets referenced in Agrell et al. (2023).

However, the wing joint presented a challenge to interpretation due to artifacts observed in the scans, likely caused by the presence of metal elements such as nails or fasteners. These beam hardening artifacts, common when scanning materials with significantly different densities, obscured details and made it difficult to determine whether the metal components served structural purposes or were the result of later repairs. The intensity and distortion introduced by these high-density inclusions highlight the complexity of scanning composite objects that combine materials such as wood and metal. For FT30, another Scherer instrument, the removal of the metal crown allowed for a clearer scan of the bell chamber, which was found to be better crafted than the bell of FT44. This clarity enabled a more detailed examination of the bell's construction. However, as with FT40, the butt joint suffered from similar interference caused by metal components, complicating the analysis of this section. Finally, FT50, a Grenser instrument, revealed evidence of woodworm damage, particularly in the long joint and butt joint. This preservation concern was coupled with interference from shiny metal saddles, which affected scan clarity. The scans provided critical data about the instrument's compromised structure, highlighting the need for digital restoration techniques to address areas of degradation.

Overall, the 3D tomographic scans revealed construction details and structural modifications that conventional examination methods could not access. The research team encountered imaging distortions caused by high-density materials, such as metal components, and by existing

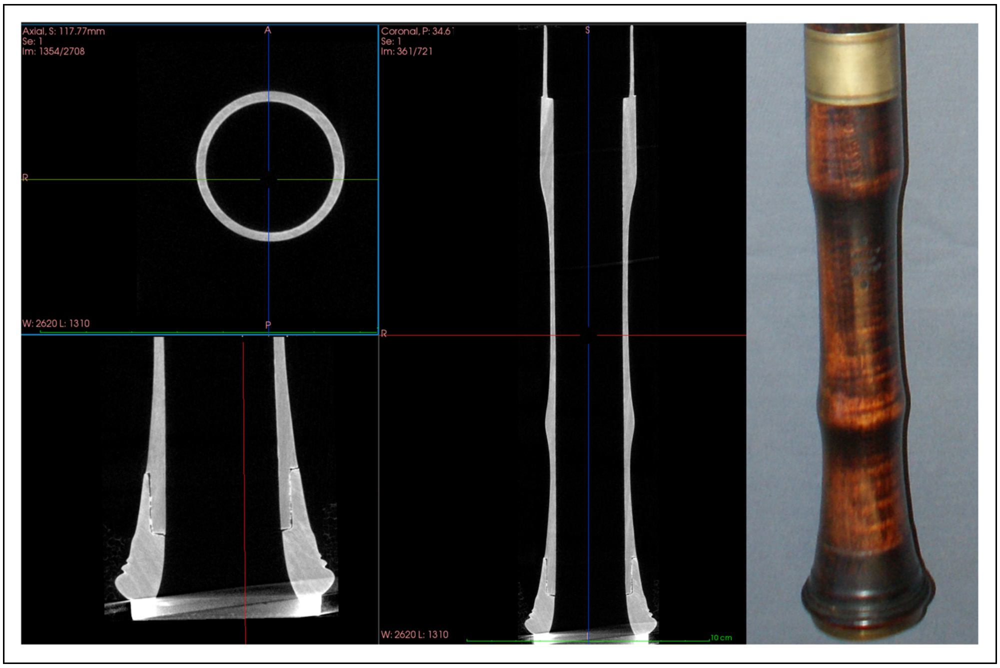

Figure 2. Detail of the construction of the bell of FT42 Savary tenoroon.

structural damage. Despite these challenges, the scans delivered precise measurements and offered valuable insights into the methods and craftsmanship behind these historical instruments. These findings support ongoing preservation and analysis efforts while emphasizing the need to refine imaging techniques to better handle materials with differing X-ray absorption characteristics.

Bore Deformation and Acoustic Implications in 3D Modeling

Using 3D printing, or additive manufacturing, can transform digital models into tangible objects by layering materials to replicate the scanned geometry. The adaptability of this technique allows the use of various materials, including wood-based composites and synthetic polymers such as nylon and polyvinyl chloride (PVC). These materials can be chosen to approximate the acoustic and structural properties of traditional woodwinds, enabling the production of playable replicas for performance research.

A major advantage of 3D printing in historical instrument research is the ability to experiment with modifications and adjustments at relatively low cost and high speed. Unlike traditional methods of making replicas by hand, which are time-consuming and prone to variability, 3D printing offers a standardized and precise means of reproduction. For example, imperfections caused by the natural ageing of wood can be digitally corrected during the modeling process before printing, restoring instruments to their presumed original condition or exploring alternative configurations.

One of the main challenges faced by instrument-makers when reconstructing historical woodwinds is dealing with the changes that occur in the material over time. Wood, the primary material for historical instruments such as the fagottino, is susceptible to physical changes due to factors such as exposure to moisture during decades of use. These changes often result in material deterioration, with a common problem being ovalization of the inner bore. Ovalization can significantly affect the acoustic properties of an instrument and presents a unique challenge when attempting to create faithful reproductions. The degree of bore deformation is influenced by several factors, including the hardness of the wood, the way the wood was initially cut, and the specific conditions under which the instrument was used and stored. For instance, harder woods such as tropical dark wood or boxwood tend to resist deformation better than softer woods such as maple. To address these challenges in our study, the precise 3D scans of the chosen historical instruments that were conducted reveal varying degrees of ovalization in their inner bores.

The scans revealed significant variations in the degree of ovalization among the instruments examined. The FT6 constructed from a hard tropical dark wood, likely rosewood or palisander, exhibited minimal ovalization. Measurements of the wing joint showed nearly identical diameters along its length, with no significant variation even in the bocal well. In contrast, the FT42 Savary Jeune, an 11-key tenoroon made of maple, displayed slight ovalization, with the most notable deformation occurring in the lower part of the wing joint, particularly between tone holes D and E. Nonetheless, the bocal well of this instrument showed insignificant ovalization.

The FT30 Scherer, a five-key fagottino crafted from boxwood, showed more pronounced ovalization throughout the wing joint. Consistent differences between the larger and smaller diameters were observed across the bore. The FT50 Grenser, a six-key fagottino made of maple, exhibited the highest degree of ovalization among the instruments studied. This instrument showed significant deformation in both the wing joint and the smallest bore of the butt joint, rendering it the most altered specimen in the study. Interestingly, the tenoroons (FT6 and FT42) presented little to no ovalization, while the fagottini (FT30 and FT50) displayed notable bore deformation, particularly in their wing and butt joints.

The 3D modeling phase revealed that ovalization affects each instrument differently, depending on the type of wood and the construction techniques used. This ovalization, which develops gradually over decades due to the natural shrinkage and warping of wood, alters both the physical geometry and the acoustic behavior of the instrument. These deformations, though subtle, can influence tuning, timbre, and response, offering insights into how materials age and how historical instruments evolve over time. Most wind instruments were traditionally crafted with cylindrical bores drilled by hand. As the wood ages, however, the inner bore often bends slightly and assumes a mildly oval shape; features that are difficult to replicate using conventional woodworking techniques. To evaluate the acoustic impact of bore ovalization, two models were created for each instrument to be later printed. As described by Simian (2025), one model retained all observed deformations, including bore ovality, while a second "round" version corrected the bore to be perfectly circular at each cross-section, compensating for wood-related distortions. The largest diameter at each point along the bore was used to guide these corrections. This method enabled a controlled acoustic comparison between the two geometries, with musicians testing both models in workshops and concert settings to assess whether and how ovalization affects performance characteristics.

This project also raised a philosophical question central to instrument reconstruction: Should historical reproductions replicate the instrument's current, aged, and deformed state, or attempt to recreate its presumed original condition? To explore this, several performance trials were conducted using both the ovalized and the corrected round bore models. Preliminary results indicated minimal differences in perceived performance, with musicians noting slight variations in response and tone color, particularly in certain registers or dynamic ranges. These differences, however, were generally regarded as minor and within the bounds of normal variation between instruments. This limited perceptual disparity may be attributable to two factors: the relatively modest degree of deformation in the original instruments selected for the study, and the inherent adaptability of skilled players to subtle acoustic changes. Notably, in these trials, several performers also acted as listeners, evaluating the instruments from the audience's perspective. Their impressions largely aligned with those of the performers, and no consistent or conclusive differences were identified between the two models. While these early findings offer valuable insights, they are primarily based on empirical evaluations in workshops and informal concert settings. Future research could benefit from incorporating quantitative acoustic analyses, such as measurements of impedance, frequency response, or airflow resistance, to more rigorously assessing how bore deformation affects sound production and performance characteristics.

Legacy and Pedagogical Applications at the Schola Cantorum Basiliensis

The fagottino project was a multidisciplinary endeavor that aimed to bridge historical research, technological innovation, and pedagogical development. It addressed multiple dimensions of historical fagottino production, including cataloguing original instruments, reconstructing them through 3D scanning and printing, and exploring their potential in educational contexts. The outcomes of the project reflect a commitment to preserving musical heritage while fostering accessibility for future generations. One of the key outcomes of the project was the production of 12 3D-printed replicas of historic fagottini, complemented by eight handcrafted wooden copies. These instruments are now part of the collection at the Schola Cantorum Basiliensis, where they are available for use by students and teachers and displayed in the online catalog (Instrumentensammlung der Schola Cantorum Basiliensis, n.d.). This integration into the resources of the Schola Cantorum Basiliensis ensures that the instruments are active tools for learning and performance, rather than mere artifacts of study.

The project prioritized investigating the pedagogical potential of the fagottino. Drawing inspiration from the use of smaller modern bassoons in early music education, the research team examined whether historical fagottini could serve a similar function. They tested the 3D-printed instruments in workshops with both children and adults and featured them in concerts to assess their playability and practical application in educational and performance contexts. The results discussed by Viola (2025) were overwhelmingly positive, suggesting that the small size and flexibility of the fagottini make them suitable for young learners. In addition, the historical context of these instruments provides an additional layer of educational value, connecting students to the music and practices of earlier periods. This aspect of the project highlighted their versatility, not only as teaching tools, but also as performance instruments. Their flexibility in tuning and intonation, similar to that of original period bassoons, further enhanced their appeal to both teachers and performers.

The project also incorporated a forward-thinking model for sustaining the use of these instruments. Recognizing that the completion of the research phase could risk relegating the instruments to storage, the team developed a pedagogical framework to ensure their continued relevance. The Schola Cantorum Basiliensis is a specialized institution offering bachelor's and master's degrees with a particular focus on early music. The master's degree in pedagogy is primarily designed to train teachers for music schools. However, owing to the institution's unique specialization in early music, the scope of these master's programs often extends beyond the original objective. As future educators, graduates are likely to teach at advanced levels, including in higher education. The affiliated music school, based on the same campus as the Schola Cantorum Basiliensis, offers tuition to young children, introducing them directly to historical instruments. This approach is distinctive in its emphasis on early exposure to period performance practices. By integrating the instruments into the Schola Cantorum Basiliensis's collection and making them available to students specializing in pedagogy, the project aims to extend the lifespan of these reproductions beyond the scope of the original research. Conversations with faculty members, such as Kelly Landerkin (K. Landerkin, personal communication, December 6, 2024) emphasized the importance of maintaining these instruments as part of the active learning environment.

At the conclusion of the fagottino project, which produced 20 fagottini, these instruments were retained within the institution to serve three primary purposes. First, they are intended for use by the Schola Cantorum Basiliensis's professional students pursuing a career in early music performance. Second, they provide a valuable resource for students on the master's teaching program, who are likely to use the fagottini during their practical training. Finally, they support the Schola's educational initiatives by enabling children to begin learning to play period instruments at an early age. In particular, the music school benefits from the expertise of Letizia Viola, a former member of the fagottino project team, as a teacher in this program.

The Problem of Pitch Standards and Original Instruments

The concept of pitch standards has undergone significant transformations throughout history, shaped by the conventions of performers, composers, and instrument-makers, and it has been fully analyzed in the monumental work by Haynes (2002). These changes have led to striking variations across regions and historical periods, even within the same era. Today, modern orchestras continue to follow different pitch standards rather than a single universal one. For example, while A = 440 Hz remains a common reference in the United Kingdom and parts of the United States, many orchestras in Germany and other Central European countries prefer A = 446 Hz. Across most of Europe, however, A = 442 Hz has emerged as the most widely adopted standard. These discrepancies highlight the inherently variable nature of pitch conventions and their dependence on regional practices and musical traditions.

In the context of early music, efforts during the 20th century established certain agreed-upon conventions regarding tuning for historical instruments. For Baroque repertoire, A = 415 Hz (a semitone lower than the modern standard of 440 Hz) became widely accepted, while for Classical repertoire, A = 430 Hz emerged as the most appropriate pitch. These conventions have been shaped by decades of scholarly research, practical experimentation, and the needs of performance practice. As a result, both original instruments and modern replicas are now crafted to align with these specific pitches, facilitating historically informed performance. However, the variability of pitch throughout history presents challenges when employing original wind instruments. Unlike modern instruments, which are designed to meet standardized tunings, historical instruments were made according to the specific requirements of their time. This means that their original tuning does not always correspond to modern conventions. In the case of fagottini, these historical variations in pitch became a notable consideration.

Initially, the pitch of the instruments selected for the study was not explicitly addressed, as the replicas were crafted based on the original dimensions of surviving instruments. The assumption was that these dimensions would provide sufficient accuracy for research purposes without requiring strict adherence to any modern tuning standards. However, determining the pitch of double reed instruments such as the bassoon, and by extension, the historical fagottini, poses considerable challenges. Critical components such as the reed, which is crafted by the performer, and the bocal, which is often interchangeable, play a significant role in pitch determination. It is common for bassoonists to own multiple bocals to adjust for pitch variations, and in historical instruments, original bocals are frequently missing or have been replaced with later versions. This was evident in the case of the four-octave fagottini studied (FT30, FT40, FT44, FT50), where none retained an original bocal or had one that could be confidently attributed to the instrument. As a result, determining their intended pitch was nearly impossible, especially given the substantial flexibility introduced by different reed and bocal combinations. In contrast, the two tenoroons (FT6 and FT42) did include original bocals, allowing for a more reliable assessment. Despite the necessity of reconstructing and adjusting the reeds, both instruments could be tuned close to A = 430 Hz, which suggests a plausible historical tuning when the bocal and reed are appropriately balanced.

The remarkable flexibility of historical wind instruments, including fagottini, is one of their defining characteristics. For bassoons and their smaller counterparts, pitch can be influenced by several factors, including the bore of the instrument, the reed, and the bocal. These elements provide the player with some ability to adjust the pitch of the instrument for different performance contexts. During the research phase, professional musicians successfully adapted the tuning of the instruments to meet modern performance standards. Baroque instruments were adjusted to A = 415 Hz, while Classical instruments were tuned to

A = 430 Hz. Some instruments, such as the tenoroon FT6 and the Savary, naturally approximated A = 430 Hz, and required only minimal adjustment to match this standard. While professional musicians were able to overcome these challenges, the situation becomes more complex when these instruments are used in pedagogical settings. Beginner musicians lack the technical expertise to navigate tuning adjustments, making it essential that the instruments they use are fundamentally tuned to the desired pitch. This need is particularly important in ensemble settings, where consistent tuning among all participants is critical for cohesive performance. Without instruments tuned to the appropriate pitch, ensemble work becomes difficult, especially for young learners.

At the end of the project, a new challenge emerged: ensuring that these instruments could be used effectively in the pedagogical environment of the Schola Cantorum's music school. While the theoretical research had not been hindered by tuning discrepancies, this issue became a significant obstacle in the context of teaching. Ensembles at the Schola Cantorum Music School typically perform at A = 440 Hz, a pitch that none of the instruments in the project were naturally tuned to achieve. Extensive testing described by Agrell (2025, p. 174) with various combinations of reeds and bocals revealed that the instruments' tuning fell within a range of A = 392 Hz to A = 435 Hz. This variation, while manageable for experienced players, proved impractical for beginners who lacked the ability to compensate for such discrepancies.

To address this challenge required a modern technological solution, specifically 3D modeling and printing, while drawing inspiration from historical practices. In the 18th and 19th centuries, it was common for wind musicians to modify their instruments to accommodate different pitch standards. This was often achieved by creating interchangeable components of varying sizes, allowing for adjustments in tuning as needed. Following this historical precedent, a shorter wing joint was developed for the tenoroon FT6, a G-tuned instrument with stable tuning at A = 430 Hz. This new wing joint was designed without keys, as they are not essential for beginners who focus primarily on mastering basic technique.

Figure 3 shows a wooden copy of the FT6 tenoroon with the modified wing joint 3D printed to allow the instrument to be tuned higher. The white wing joint shown in Figure 3, also 3D printed, is based on the original instrument, while the pink version has been proportionally shortened to accommodate the new tuning. The technical adjustments were carried out by Ricardo Simian. The results of the modified wing joints were highly successful. The altered instruments achieved stable tuning at A = 440 Hz, making them suitable for use by children in the pedagogical environment. By combining historical methods with modern technology, the project ensured that these instruments could be integrated into the Schola Cantorum's music School, allowing young musicians to participate in ensemble performances.

Figure 3. 3D-printed fagottino wing joints on a wooden jagottino. Photo by the author.

Conclusion

The integration of digital technologies in historical musicology has demonstrated significant transformative potential, as evidenced by pioneering projects such as the fagottino project. While these innovations are currently confined to large institutions and specialized research contexts, their foundational work in developing standardized methodologies for measurement and 3D printing has laid the groundwork for broader applications. These efforts, enabled by collaborations between researchers and industrial innovators, showcase the dual capacity of these technologies to preserve fragile instruments and make them accessible for scholarly research.

The fagottino project exemplifies the intersection of traditional craftsmanship and modern technological tools, emphasizing the value of interdisciplinary collaboration. By addressing both the theoretical and the practical aspects of historical fagottini, the project has not only preserved an important segment of musical heritage but also set a precedent for similar initiatives in the future. The instruments produced, coupled with the extensive documentation and methodologies developed, serve as a blueprint for historical reconstruction projects and demonstrate the educational potential of 3D-printed replicas.

Looking ahead, the long-term impact of this project is likely to extend beyond its immediate outcomes. The integration of 3D-printed instruments into educational settings, such as their current use in the Schola Cantorum Basiliensis, indicates their potential to enhance pedagogy and foster a deeper understanding of historical performance practices. As these technologies become more widely adopted, their applications in education, performance, and research are expected to expand, further bridging the gap between historical authenticity and contemporary accessibility.

Technologically, the project demonstrated that CT-based scanning combined with digital modeling and SLS printing yields high-fidelity reconstructions suitable for both acoustic testing and performance. Comparative testing of ovalized versus idealized bore geometries showed minor, yet perceptible, differences in tone quality and response, validating the feasibility of both historical and "corrected" reconstruction strategies. Furthermore, the use of modular digital files allowed rapid iteration and tuning adaptation, including the successful production of shorter wing joints for pedagogical tuning standards. These outcomes illustrate the technical viability and reproducibility of this method, suggesting it can be standardized and adapted for broader applications in instrument reconstruction.

Ultimately, the fagottino project illustrates how the synergy of historical expertise and technological innovation can generate meaningful contributions to both scholarship and education. It stands as a model for future interdisciplinary endeavors, demonstrating that historical musicology can achieve tangible, lasting impacts by embracing modern tools and innovative teaching strategies.

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Data Availability Statement

The datasets generated and analyzed during this study are available in the research team's DaSCH repository (Agrell et al., 2025).

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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