THREE-DIMENSIONAL COMPUTED TOMOGRAPHY IN ORGANOLOGY

Beatrix Darmstädter

Curator, Collection of Historic Musical Instruments, *Kunsthistorisches Museum,* Vienna
beatrix.darmstaedter@khm.at

Keywords:
3D-CT, organology,
geometric measurement,
musicology,
museology

Article history:

Received 15 Oct. 2015
Revised 15 Jan. 2016
Accepted 12 Feb. 2016

Abstract
The Collection of Historic Musical Instruments (Kunsthistorisches Museum, Vienna*) has gained extensive experience in 3D-CT-based inspection, rendering, visualization and measuring of unique, fragile items and museum exhibits due to two large research projects it has supervised since 2007. The project supported by the Austrian Science Fund (FWF) focussed on a broad group of Renaissance wind instruments (18 cornetti, a serpent, six crumhorns and a wind cap shawm). The research objective was the exact calculation of all acoustical and structural parameters that are not accessible without using a 3D-CT non-destructing test procedure to enable realistic reproductions of the musical instruments by instrument makers. The other project, supported by the* OeNB-Jubiläumsfonds, *is still in the implementation phase, and aims to document the conservational condition of precious violins and to demonstrate the contingent deformation of recently made violins' constructional parts within a long term playing. The present survey informs about the different high-technological devices used for the examination of historic musical instruments and reports on the research findings.*

1 Introduction

The Collection of Historic Musical Instruments (SAM) in Vienna focusses on the development and application of 3D-CT methods in organology since 2004. At that time, the scientists of the SAM made first experimental scans and two-dimensional renderings of a curved cornetto and a violin using a spiral CT device for medical examinations at the University of Veterinary Medicine in Vienna [1]. The low radiographic dose ideal for animate beings, the 2D-renderings in form of stacked slices, and rather poor software tools for recalculating multidimensional inner volumes offered indeed initial insights into the magnificent world of CT-measuring but shaped up as insufficient for the purposes in the field of organology. Thus, the SAM concentrated on applying CT devices engineered for industrial non-destructive material analysis and performed the worldwide first serial examination of historic musical instruments from 2007 to 2009.

2 Propaedeutic considerations

In museums, the use of x-ray and CT devices for detecting invisible inner-lives of fragile historical objects is inseparably linked to the researcher's daily routine. Scientists and restorers interpret meaningful data gained by evaluating x-ray photographs since generations, and they work with 3D renderings of the museum pieces whenever this modern technique is available. Although the application of 3D-CT is considered as advantageously, it still is quite restricted because vast user fees arise and a specialized staff is required to ensure an appropriate operation of the high-tech devices. The application of 3D-CT is, in most instances, contingent upon an extensive research funding — to master this first hurdle, scientists elaborate in-depth proposals. These papers specify the reasons for such an expensive examination and in case of valuable, unique museum objects the facts that 3D methods are non-destructive, (according to current knowledge) harmless to the historic items and very conservative modes of survey often outweigh the disadvantages of being costly and personnel intensive. In museums, the best possible preservation of the cultural heritage is an absolute must and every risky manipulation of the objects therefore should be avoided.

When planning an examination of museum items by using 3D-CT, one has to take into account that the highest security standards are guaranteed in the examination room and in its surroundings. These include permanent supervision by watchmen or cameras, secure and lockable storage as well as fire prevention. In addition, one has to make allowances for adequate climatic standards, as a well-adjusted room temperature and a room humidity that meets the requirements of the particular objects. If a transport from the museum or an art depository to the place of the CT device is necessary, a “nail to nail” art insurance contract has to be taken out, and, if possible, an art carrier should be charged.

A careful project preparation implies a close inspection of the conservational condition of the museum objects selected for CT examination. Particular caution must be exercised when the object is in a poor state of preservation, the whole item or parts of it are fragile and the object consists of different, detachable parts. The latter not only asks for a careful handling in general but also for utmost caution when setting up and fixing the object onto the rotary table in the event of using scan devices where the specimen is continuously moved. When CT devices with tight or closed cabins are used, there is always a residual risk of a (minor) temperature increase within the cabin during the examination. A special monitoring should be established to prevent harm to the specimen and to avoid disturbing influences on the scan and further measurement process. Attention should be paid to the material composition of the object. Scientists cannot offset the artefacts based on serious variations in density (e.g. metal in or on wood) by adjusting the filters of the x-ray source or by modifying the software settings before rendering — they can only reduce them.

In organology, we benefit from the enriching possibilities of 3D-CT methods by multi-dimensional measuring, 2D and 3D visualization, analyzing of material and constructional parameters, detecting invisible macroscopic and microscopic damages, comparing morphological alterations put down to long-term playing, and calculating the progress of inner bores or the parameters of inaccessible interior spaces. This allows conclusions to be drawn as to the acoustics of the analyzed instruments. In special cases, instrument makers gain data for reproducing original musical instruments by 3D printing or computerized numerical control, and wood researchers use the visualizations of the scanned wooden structures to identify and count the tree-rings for dendrochronology. Restorers have the opportunity to plan interventions by means of computer simulations and they can long-time monitor the condition of certain objects in all microscopic details — even in complete secluded areas.

3 The project on woodwind instruments

The Collection of Historic Musical Instruments of the *Kunsthistorisches Museum* Vienna is world-famous for its Renaissance instruments, and within this set of objects the wind instruments play a very important role. In conjunction with the Early Music movement(s) the museum instruments were copied and reproduced for their use in historical music performance. Instrument makers regularly ask for reliable measurements and for additional information on constructional and physical parameters, pitches and material. In some cases, the museum could not provide them with detailed information because the design and construction of certain instruments were too intricate for manual measurement and the analysis of the historic material at inaccessible sections could not be performed. Furthermore, one could not ascertain acoustical characteristics and pitches as these instruments are not to be played anymore for the sake of their conservation.

Eventually, the screening and measurement by 3D-CT was of great value to the scientists and to the instrument makers.

The project of 3D measurement of wind instruments was the first serial examination of historic musical instruments worldwide. It was funded by the Austrian Science Fund *(FWF)* and was carried out in co-operation by the Collection of Historic Musical Instruments and the *Fachhochschule Oberösterreich,* Campus Wels from 2007 to 2009. The project leader was Beatrix Darmstädter, who could rely on the expert knowledge of Dietmar Salaberger and his team operating the 3D-CT device located in Wels. Within nine days 18 cornetti, a serpent, six crumhorns and a wind cap shawm have been scanned. Except of one instrument — an s-shaped cornetto of the Mahillon-workshop made at the end of the 19th century — all instruments were made in the (late) Renaissance. The work on the data preparation and evaluation, the measurement as well as different renderings took approximately one and a half year. The most important goal of this research project and one of the most progressive achievements in modern organology was the processing of an algorithmic measurement method.

This method enables the user to applicate a scientifically legitimate, reproducible computerized measurement process instead of variable measuring results by using the common snap to grid functions that, sometimes, induce significant measurement inaccuracies from 0.5 to 1.0 mm because of the different perception of pixel-structures on the screen by the human eye. To define the geometrical data of the specimens software was created that calculated the grey value profiles automatically [2]. For the project on Renaissance wind instruments Darmstädter and Salaberger used a RayScan 250E with a x-ray source that works with a maximum of 450 keV. To receive scans of very high precision up to 5µm, a micro-focus of 225 keV is provided. The specimen is positioned on a rotary table turning very slowly through 360°. For their research purposes, they equipped the device to obtain volume pixels (voxels) from 100 to 275 µm [3] and from 35 to 250 µm [4] — dependent on the musical instrument's dimensions and the resolution they needed for their further organological research. The standard software for the data evaluation and measuring was VG Studio MAX 2.0; additional renderings and visualizations of constructional details have been made with OsiriX 3.7 [5]. For musical instruments of larger size, like the serpent SAM 237, measuring circuit extensions have been performed [6].

The most important research results for the organological community and the instrument makers were the detailed measurements of the inner bore that comprised, in the most complex case, the serpent SAM 237, 458 single measuring values. Wherever striking irregularities of the bore's progression occurred, the x-shaped measuring mode (from NW to SE and NE to SW) was expanded to get supplementary information on measurements in the +-shaped direction (from N to S and W to E), whereas potential outliers caused, for instance, by the openings of the finger holes, have been made ineffective. In addition, Darmstädter and Salaberger recalculated oval or erratic passages to the form of regular circular diameters to facilitate their usability in today's instrument making [7].

Wherever possible and scientifically conclusive, they interpreted the acoustical and physical assets of the instruments. Regarding this, the *cornetti muti* with integrated mouthpieces were of special interest and provided a serious basis for acoustical research. In these cases, the impedance was measured and musical characteristics have been deduced from the data. For this purpose, they used the software BIAS 6.2.3 (and VIAS 6.2.3) [8]. So, they got objective information about the pitch, the tuning and about individual musical qualities of the original instrument that allows musicologists and musicians to assess the musical employment of the particular original instrument in history.

In the course of the project, material analyses could be made where macroscopic and conventional examination methods frequently had failed. In particular, the type of wood used for manufacturing the covered curved cornetti could be stated in most of the cases, and the material of the dark cover was analysed in cases where uncertainty existed [9].

Finally, unexpected constructional details and information about makers came to light. Darmstädter and Salaberger proved, for instance, that the maker of the serpent SAM 237 put 30 segments together to form the s-shaped body of the instrument. The segments were agglutinated and the whole corpus was covered with leather to achieve a high stability. The first bending of the instrument, were the musicians usually take the serpent to carry it, the maker reinforced the body by additional material — probably a sinew of a cattle — fixed between the wooden corpus and the leather cover [10]. As it would appear, the observation by Marin Mersenne conformed to the then standards in serpent making [11]. Interestingly, one curved cornetto, SAM 236, that was regarded as "unsigned" since the foundation of the collection could be attributed to the workshop of the Bassano dynasty. Under the historic but obviously not original cover, the mark of two silkworm moths emerged when viewing the visualizations and using certain filters. On account of the fact that the number auf original curved cornetti signed by certain instrument makers or attributed to concrete workshops is very small, this unexpected discovery is very determinant [12].

An advantageous „side effect" of the 3D-CT method is to get the most precise conservational object documentation possible. In several cases, the complete degree of damages known and ex ante observed macroscopically on the surface of the instrument became visible. After the data evaluation of the wind cap shawm SAM 177 it became apparent that the condition of this item is extremely bad. The whole corpus is exceeded with wormholes, and every kind of manipulation will in future seriously jeopardize this unique instrument [13]. Moreover, the 3D-CT examination made it possible to detect whether a historical instrument has been played in modern times. Normally musicians who tried out the museum instruments in the 20th century impregnated their inner bore with oil to protect the instrument against cracks caused by the humidity of the breath and the dry process hereinafter. However, they did not use linseed oil or other substances already existing in former epochs but they took heavy paraffin oils to avoid possible mould formation. Such modern substances that conglomerated with dust, saliva and water condensation are still evident through 3D-CT because their density impedes an absorption by the wood [14].

4 The project on stringed instruments

Since 2013, the SAM is involved in the research project "Violin Forensic" headed by Gerhard Weber from the department of anthropology of the University of Vienna and Rudolf Hopfner who manages the Collection of Historic Musical Instruments of the *Kunsthistorisches Museum* Vienna. The main content orientation of this project is to document morphologic changes in historic violins and violas during their playing process. Other issues are the inspection of museum items to trace back modifications and modernisations usually befalling excellent stringed instruments within their history. Moreover, internal damages, like wormholes, cracks, repairs become obvious, and individual features in instrument making can be proven. Of course, instrument makers and scientists benefit from coloured thickness measurements — the most demanded information on the sector of stringed instrument making — and elevation maps giving additional insight into instrument making. This project is funded by the *Jubiläumsfonds* of the Austrian National Bank that, by the way, holds one of the most important collections of stringed instruments for use. Renowned Austrian and international soloists as well as members of well-known orchestras play the instruments of this exclusive collection.

Weber and Hopfner use the micro-CT device Viscom X8060 with individually programmed software and Amira 5.4.3. The CT device is located at the "Vienna Micro-Lab" of the University of Vienna. This device is normally applied to scan zoological and anthropological specimens. As this device is not open but the test piece is put inside a tight cabin, the dimensions of the musical instruments must be considered meticulously. The scanner's range extends from four to 80 µm and it takes approximately 11 hours to scan the body of one violin with the resolution of 70 µm.

The most outstanding individual project so far concerns the viola by Girolamo Amati held in the Este Collection, Modena. This instrument came into the collection in 1884. The viola was made around 1625, and it was for the first time modernized in the 1790s by the German instrument maker Jakob Steininger [15]. The micro-CT scan makes individual quality characteristics visible, like the typical "Amati pin" found in the centre of the instrument backs made by members of the Amati dynasty. After rendering this pin occurs brighter than its wooden surroundings, so it consist of very dense wood. One understands the manner Girolamo Amati cut the linings and designed the edgework. The different structures of wood clearly indicate, as usual, spruce and maple for the body and — exceptionally — willow for the blocks and linings in this particular case [16]. With the help of micro-CT Hopfner examined the section of the upper block and the neck foot in detail, and he concluded that the viola originally had three nails. Possibly two of them had been reused after resetting the neck. The two nails sit on the centre line of the block and they run through the doubling and the original part of the block, and stick in the neck foot. Some remains of the third nail are still visible in its former position [17]. As Hopfner could observe, the six blocks of the viola are from the same piece of wood, and so he assumed that they are original [18].

The CT visualizations enable Hopfner to measure the instrument’s back and belly with an accuracy of 0.1 mm. He created thickness matrices with a 2 x 2 cm grid using the advantages this method can offer: The exact point where the measurement is taken can be determined with algorithmic precision and points that are not accessible with manual measuring tools, for instance areas around the edges, can be measured. Moreover, one always receives the information whether a measuring point is located on original wood or on a cleat, reinforcement or doubling. In addition, Hopfner calculates elevation maps for the belly and back, showing elevation contours similar to geographical contour maps [19]. These elevation maps of outstanding explanatory power make the arching shape and irregularities of the height profiles transparent and provide another basis for a better understanding of the physical forces that have an effect on the individual acoustics of legendary stringed instruments made by celebrated instrument makers.

5 Outlook on the future

Following the Collection of Historic Musical Instruments, other leading European institutions that preserve historic musical instruments, like the *Germanisches Nationalmuseum* in Nuremberg (project “MUSICES”) [20], emphasize on the mighty tools of 3D-CT methods. It is conjecturable that in future museums and collections will do a high percentage of object documentation and measurement by using 3D-CT procedures. The new challenges that they will have to cope with are the enormous extension of the storage spaces and the changeover and retrofitting of the computer systems in the museums and collections to enable the unlimited use of adequate software in their offices. Above all, greater involvement of CT methods and CT-data processing in the professional training of curators and restorers will be required.

References

[1] Beatrix Darmstädter: *Einleitung,* in: Die Zinken und der Serpent der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 7, ed. by Sabine Haag, Vienna-Bergkirchen 2011, p. 11.

[2] Beatrix Darmstädter, Dietmar Salaberger: Integral Curve versus Separate Bell. Aspects on the Construction Modes of Crumhorns, in: Proceedings of the CIM09 (Paris 2009), [Online:] http://cim09.lam.jussieu.fr/CIM09-en/Proceedings.html, p. 2–3 [Accessed: 20-November-2015].

[3] Dietmar Salaberger: *Bestimmung von Geometriemerkmalen mit Hilfe der industriellen Computertomographie,* in: Die Krummhörner und die Windkapselschalmei aus der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 8, ed. by Sabine Haag, Vienna 2015, p. 118.

[4] Dietmar Salaberger: *Bestimmung von Geometriemerkmalen mit Hilfe der industriellen Computertomographie,* in: Die Zinken und der Serpent der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 7, ed. by Sabine Haag, Vienna-Bergkirchen 2011, p. 112–113.

[5] Beatrix Darmstädter: *Konventionen zur Katalogisierung,* in: Die Krummhörner und die Windkapselschalmei aus der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 8, ed. by Sabine Haag, Vienna 2015, p.131.

[6] Beatrix Darmstädter, Dietmar Salaberger: *Erste Ergebnisse der 3D-röntgencomputertomographischen Untersuchung an Blasinstrumenten der Sammlung alter Musikinstrumente,* in: Technologische Studien Kunsthistorisches Museum, vol. 5, ed. by. Martina Grießer, Elke Oberthaler, Alfons Huber, Vienna 2008, p. 111–112.

[7] see [6], p. 134–137.

[8] Beatrix Darmstädter: *Konventionen zur Katalogisierung,* in: Die Zinken und der Serpent der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 7, ed. by Sabine Haag, Vienna-Bergkirchen 2011, p. 121.

[9] Beatrix Darmstädter, Dietmar Salaberger: *Katalog,* in: Die Zinken und der Serpent der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 7, ed. by Sabine Haag, Vienna-Bergkirchen 2011, p. 185–227.

[10] see [9], p. 231.

[11] Marin Mersenne: *Harmonie Universelle contenant la Théorie et Pratique de la Musique,* vol. 3, Paris 1636 [facsimile CNRS 1986], p. 278.

[12] see [9], p. 217.
[13] Beatrix Darmstädter, Dietmar Salaberger: *Katalog,* in: Die Krummhörner und die Windkapselschalmei aus der Sammlung alter Musikinstrumente, ed. by Beatrix Darmstädter, Sammlungskataloge des Kunsthistorischen Museums, vol. 8, ed. by Sabine Haag, Vienna 2015, p. 139.
[14] see [9], p. 199.
[15] Rudolf Hopfner, Andrea Zanrè: New Light on an Uncut Diamond, in: The Strad, October 2014, no. 1494, p. 36.
[16] see [15], p. 40.
[17] Rudolf Hopfner: Micro-CT Scan of the Girolamo Amati Viola: a forensic examination, in: The Girolamo Amati Viola in the Galleria Estense, ed. by Andrea Zanrè, Treasures of Italian Violin Making, vol. 1, Parma 2014, p. 44–45.
[18] see [17], p. 44.
[19] see [17], p. 47–48.
[20] see [Online:] http://www.gnm.de/forschung/forschungsprojekte/musices/ [Accessed: 23-November-2015].