

# Chapter 5

## Technology for Technology's Sake: The Technical Study of Gothic Miniature Boxwood Carvings in the Thomson Collection at the Art Gallery of Ontario



Lisa Ellis, Alexandra Suda, Ronald Martin, Elizabeth Moffatt,  
Jennifer Poulin, Heidi Sobol, Priam Givord, Craig Boyko, Ian Lefebvre,  
and Andrew J. Nelson

**Abstract** This paper describes the evolution and results of a technical study that focused initially on the Thomson Collection of miniature boxwood carvings at the Art Gallery of Ontario (AGO). This work eventually became the AGO's impetus for its participation in an international exhibit "Small Wonders," organized with the Rijksmuseum and the Metropolitan Museum of Art. The technical work on early sixteenth century miniature boxwood carvings, which includes both prayer beads and miniature altarpieces, started with X-radiography at the Royal Ontario Museum, followed with in-house photography using a cutting edge but now somewhat more common specialized macro set-up, and ultimately micro-computed tomography (CT) scanning, or high-resolution X-ray micro-computed tomography at Sustainable Archaeology, Western University, London Ontario and Advanced 3D Analysis software (ORS) at the AGO. Secondary digital files were used in "Small Wonders: the VR Experience," wherein users could enter into a dramatically magnified virtual prayer bead. Scientific analysis of a selection of the artifacts' coatings, polychromy and adhesives was undertaken by the Canadian Conservation Institute using Fourier

---

L. Ellis (✉) · A. Suda · C. Boyko · I. Lefebvre  
Art Gallery of Ontario, Toronto, ON, Canada  
e-mail: [lisa.ellis@ago.ca](mailto:lisa.ellis@ago.ca)

R. Martin · A. J. Nelson  
Departments of Anthropology and Chemistry, The University of Western Ontario,  
London, ON, Canada

E. Moffatt · J. Poulin  
Canadian Conservation Institute, Ottawa, ON, Canada

H. Sobol  
Royal Ontario Museum, Toronto, ON, Canada

P. Givord  
Computational Designer, Toronto, ON, Canada

transform infrared spectroscopy (FTIR); scanning electron microscopy-energy dispersive spectrometry (SEM-EDS); thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS); and Raman spectroscopy.

**Keywords** Technical study · Boxwood · Miniature carving · Prayer beads · Nuts · Micro CT scanning · Advanced 3D analysis software

## 5.1 Introduction

This paper presents the results of several years of interdisciplinary collaborative research on a corpus of sixteenth century objects of religious devotion (*small wonders*). These objects include prayer beads and miniature altar pieces that are united by the presentation of remarkably intricate scenes microcarved in boxwood. Starting as a focused study on the Thomson collection of Gothic boxwood miniatures at the AGO, the study ultimately made a significant contribution to a major international exhibition, “Small Wonders,” shortlisted in 2017 by Apollo Magazine as an “Exhibition of the Year.” The exhibition generated two print catalogues [1, 2], one of which was recognized by the New York Times as one of “The Best Art Books” of 2017; an online database which won “Outstanding Digital Publication” in 2017 by the Association of Art Museum Curators; and a virtual reality experience which was awarded an Honorable Mention Media and Technology MUSE Award by the American Association of Museums. The AGO also received the Canadian Museums Association’s Conservation Award of Outstanding Achievement in 2017 for its critical role in the development of the “Small Wonders” (Fig. 5.1).

The success of the gothic boxwood miniature research project and its reception owes a great deal to timing, technology and teamwork. Technological developments perfectly meshed with research goals: the size and complexity of the artworks being studied were perfect subjects for the scientific instrumentation and software available. While access to micro-CT instrumentation initially presented some challenges, developments in desktop computation meant that the datasets of the artworks could be manipulated by the principal investigator in the conservation studio in close proximity to the objects [3]. The photographers’ software and related hardware improved to such a degree over the course of the project that the scope of their work was able to expand significantly due to the exponential reduction of the hours necessary for post capture processing. At the same time, the technologies used to study the boxwood miniatures also acted as vehicles that allowed the public to gain access to these beloved carvings in a variety of media, namely the on-line database, featuring high resolution images; two print catalogues featuring these images and outlining technical findings [1, 2]; animations created using micro-CT data and revealing construction techniques; and a virtual reality (VR) experience into which the viewer virtually enters into and deconstructs one of the Thomson Collection prayer beads.

Initiated as a collaborative project at the AGO between curator Alexandra Suda and conservator Lisa Ellis, this research focused on the world’s largest collection of



**Fig. 5.1** Small Wonders exhibit at the Art Gallery of Ontario, November 5, 2016–January 22, 2017

early sixteenth century boxwood miniature carvings, found in the Thomson Collection of European Art at the AGO. Both were intrigued by the mysterious construction of these objects, as are the majority of museum visitors who notice the tiny artworks in the many museums where they are presented as *objects of wonder*. As the scope of the initial research project expanded, additional researchers with specialized imaging and analytical skills and corresponding instrumentation joined the team from the Chemistry and Anthropology Departments at the University of Western Ontario; the Royal Ontario Museum; and the Canadian Conservation Institute (CCI).

Contained within the Thomson collection of European Art at the AGO, the objects of interest are ten late Gothic/early Renaissance Northern European prayer beads, two associated miniature altarpieces, and a later, seventeenth century Italian group of even tinier carvings by Ottaviano Jannella (Fig. 5.2). The entire group was investigated with the goal of understanding the intricacies of construction and potentially identifying production workshops and perhaps even individual sculptors of the sixteenth century works. Greatly outnumbering the other types of objects, the prayer beads showed promise in answering the question about their makers: there appeared to be several different kinds of these objects, characterized by different construction techniques and therefore likely made by different workshops and sculptors.

The micro-CT scanning and resulting images processed with Advanced 3D Analysis software produced very promising material early on in the project's evolu-



**Fig. 5.2** View of Thomson Collection miniature Gothic boxwood carvings on permanent view at the Art Gallery of Ontario

tion. Findings were shared with other museums with similar objects in an effort to persuade them to research their own collections in a collaboration with the AGO. A major travelling and international exhibition called “Small Wonders” was created by curators Alexandra Suda (AGO), Barbara Boehm (Metropolitan Museum of Art (the MET)) and Frits Scholten (Rijksmuseum) to showcase their collections. At that time, Pete Dandridge, Conservator, Department of Objects Conservation at the MET joined the technical research project. His extraordinarily deep experience in understanding the manufacture of medieval objects along with materials and restoration practices perfectly complemented the research underway. The technical investigation of the works was published jointly by Ellis and Dandridge in a chapter in the exhibition catalogue [2] and in a guidebook to the collections of the AGO and MET [1].

AGO photographers Craig Boyko and Ian Lefebvre travelled around the world to capture high resolution images of as many of the miniature boxwoods as possible to be used first in research, exhibition didactics and marketing, and ultimately in the two major publications associated with the project and the on-line database. The objects were shot using the same light source and camera and processed with the same software in a predetermined set of views in such a way as to allow the resulting images to be comparable. The photographs are now available in a publicly accessible database ([ago.boxwood.ca](http://ago.boxwood.ca)) which operates using IIIF, the International Image Interoperability Framework ([iiif.io](http://iiif.io)), designed to allow experts and novice users to view, compare and annotate the high resolution images.

## 5.2 Description of the Thomson Collection Prayer Beads

Two of the Thomson prayer beads are carved in the shape of human skulls. The remaining eight are more or less in the form of two hemispheres joined at their equators with a wide band, the outside diameters of which range from approximately 3–10 cm. The exteriors of the prayer beads are pierced with ornate patterns inspired by gothic tracery. Some have Latin scripts carved around their circumference. All are hinged with metal pins. While some retain what appear to be original fittings made with precious metals, such as escutcheons and chains, others have been stripped of these or sport newer restored hardware. Opening the objects reveals minutely sculpted reliefs which are held by pegs in the hollowed out hemispheres that make up the outer shells. Close inspection reveals that some of the reliefs are composed of are comprised of numerous wooden elements joined together, some more subtly than others and some with indiscernible joinery.

While the sculpted, pierced exteriors of the prayer beads are impressively delicate and beautiful, they were designed to protect the even more fragile interiors of the beads that have been proven to be awe inspiring and unforgettable to the AGO's and other collections' visitors, and presumably previous owners. The more simply constructed beads' interiors consist of a single, circular plane of wood into which a low relief has been carved. The more complex prayer beads' interiors, however, are made of a number of elements, some impossibly small and delicate such as spears and flagpoles, which appear barely thicker than a hair. The reliefs bring to life narrative scenes, mostly Christological, which grab the viewer's attention: many of the tiny figures in the foregrounds are almost completely carved in the round. Tiny groupings in low relief in the background are typically obscured by closer elements which defy and frustrate the viewer's desire to understand their construction (Fig. 5.3).

Ellis and Dandridge ultimately used micro-CT scanning coupled with Advanced 3D Analysis software along with close examination to determine that there are two strategies at work in the complex prayer bead relief scenes [1, 2]. Some of the scenes are carved into of joined layers or discs of pierced boxwood that are held within the outer tracery carved shell by tiny pegs. Some of the interior carvings use a more or less single shell of boxwood into which strategically placed cutouts allow the carver to access areas that would otherwise be impossible to reach with tools if the carving was worked only from the front. The cutouts or "windows" thus created are subsequently filled with carved elements and are then held in place with joinery and/or pegs. The most complex interior reliefs are made up of three to five major interlocking elements with sometimes tens of additional elements used to further embellish the final composition, such as spikes, stars and buttons which are pressure fitted into drilled holes (Fig. 5.4).

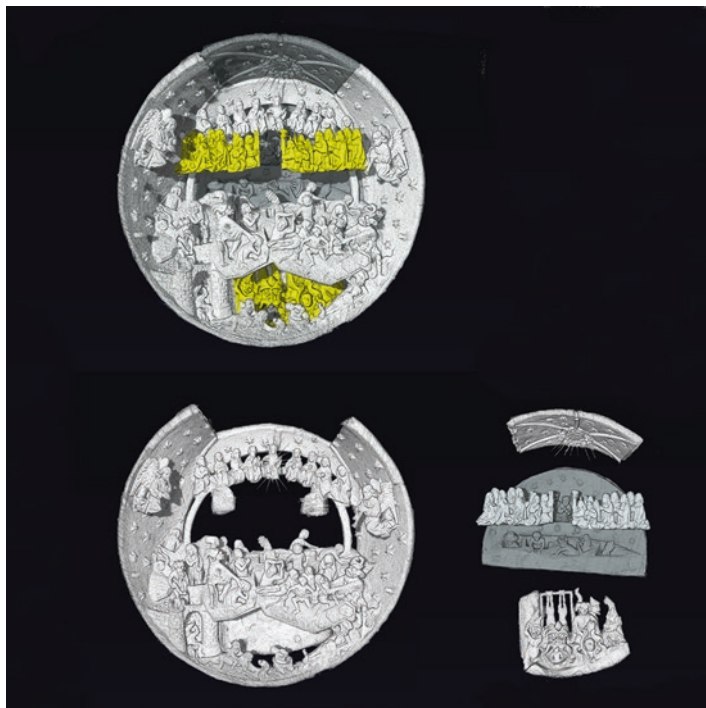
**Fig. 5.3** Prayer bead.  
AGO ID 29365. The  
Thomson collection at the  
Art Gallery of Ontario



### 5.3 Examination Using Microscopy and Macro Photography

Visual examination of the prayer beads can be frustrating, depending, of course, on the viewer's eyesight and available lighting. The works are of such a small size that for many, only the general composition is evident, particularly when the objects are viewed within a museum vitrine. For the smallest carvings, sometimes even the number of figures and objects portrayed can be difficult to discern. While the construction of the simpler prayer beads is evident upon close examination, many of these exquisite wooden carvings were only understandable once they had been micro-CT scanned. Not only are the objects tiny, but the sculptor intentionally obscured the joins for the cutouts in the most sophisticated examples.

The need to search for more powerful imaging tools became evident long before the inception of the project in 2011. Closer examination at the AGO by Ellis who first encountered the works in 2007, began with a Zeiss stereo microscope, with a maximum magnification of 20 $\times$ . While she was able to manipulate objects to gain better viewing angles along with improved fiber optic lighting to understand composition and clues of construction, such as pegs and joins, it was impossible to see some of the joins and intersections of the interlocking pieces the sculptor had carefully hidden from sight. Perhaps most frustrating were the tantalizing glimpses made available through ages old lacunae in the prayer beads' outer shells that only partially revealed construction methodologies.



**Fig. 5.4** Prayer bead. AGO ID 29365 Rendering of upper relief created using ORS Advanced 3D Analysis software and micro-CT scan. Composite parts in shades of grey and yellow shown together at top; bottom views show same relief separated into its major components digitally

## 5.4 Specialized Photography

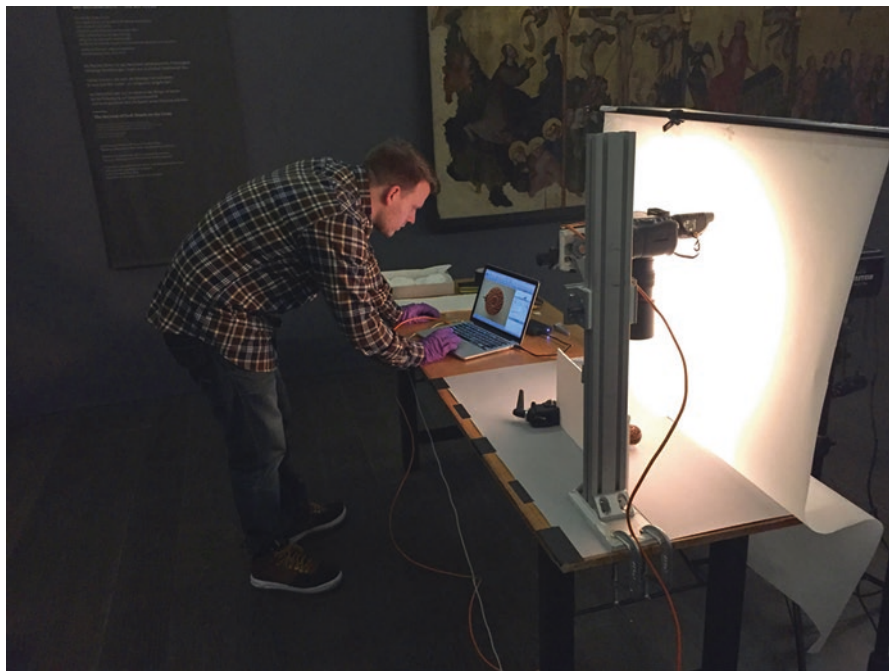
One of the surprising and contradictory aspects about understanding such diminutive art objects is the difficulty in appreciating the work as a whole. As the tiny scale of the carving requires microscopy to discern details pertinent to the scenes being depicted, and the overall composition can be lost to the viewer. An obvious solution to this is to have macro photographs for reference. However, there are significant challenges in photographing small, detailed objects with deep relief, such as the prayer beads. Using a traditional photography setup, the resolution of the image is sacrificed, as the small aperture required to achieve the desired depth of field results in a softer image. The diminutive size of the prayer beads results in poor quality images where entire passages may be lost in haziness.

In order to overcome these obstacles, the AGO photography department started using a technique called focus stacking: this was a cutting edge technology at the start of the project, and has now gained wide acceptance in commercial and museum photography studios. In this technique, a single photographic image is assembled from a series of images, each focused on a different incremental plane through the

depth of the object. The images are shot with a wide aperture in order to reduce diffraction.

The AGO's photography department used a Phase One 645DF camera body, 120 mm Phase One Macro lens and the Leaf Aptus-II 12 digital back to produce 80 megapixel images with files sizes ranging around 250 MB. While focus stacked images were once assembled manually in different computer applications, it was a time-consuming process which, depending on the operator, could take hours for a single image. A number of different focus stacking applications, including Adobe Photoshop, were tested at the AGO and the results compared. The purpose-built focus stacking software, Helicon Focus, yielded the most reliable images, perhaps due to its wide variety of adjustable parameters. The resulting macro photographs of the prayer beads are phenomenal, and of such fine resolution that they can be increased to poster size without loss of detail (Fig. 5.5).

The research value of this kind of imaging was immediately clear. The photographers, along with input from the rest of the AGO team, developed a style guide, outlining equipment, lighting and views of the object to be captured, to share with other institutions so that comparable images could be produced. While some of the larger institutions with dedicated photo studios, such as the MET, committed their own resources to the project and were able to follow the style guide, other institutions granted access and makeshift studio space to the AGO photographers Boyko



**Fig. 5.5** AGO photographer Craig Boyko in a makeshift studio capturing high resolution stacked images



and Lefebre. These include the Art Institute of Chicago; Bergbau und Gotikmuseum, Leogang Austria; Detroit Institute of Arts; Devonshire Collection, Chatsworth; Kunstgewerbemuseum, Staatliche Museen zu Berlin; Loyola University Museum of Art; Musée du Louvre; Museum Catharijneconvent; Mayer van den Bergh Museum, Antwerp; Museum voor Religieuze Kunst; The Wernher Foundation, English Heritage, Ranger's House, London; Rijksmuseum, Amsterdam; Seattle Art Museum; Staatliche Kunstsammlungen Dresden; The State Hermitage Museum; Thyssen-Bornemisza Collections; Victoria and Albert Museum; and the Wallace Collection.

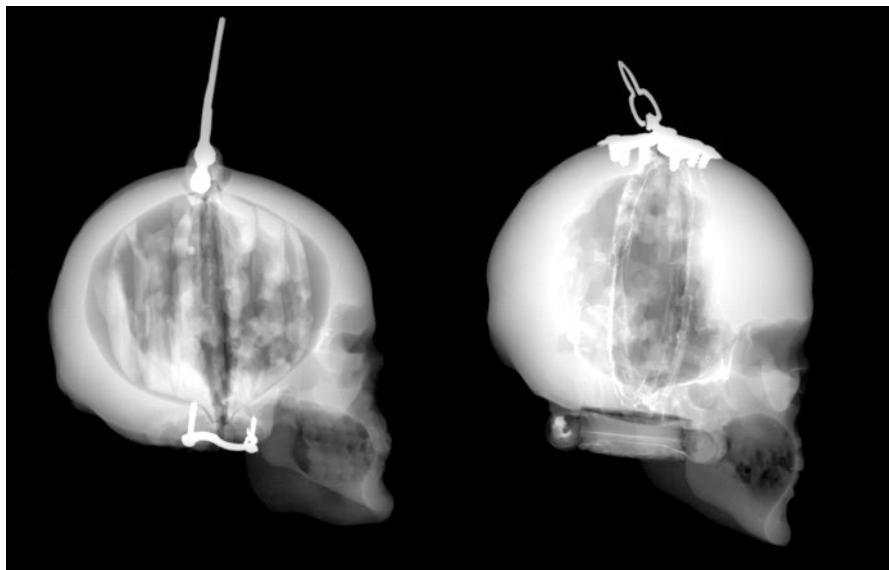
## 5.5 X-Radiography

The first attempt to understand internal features of the miniature boxwoods began with X-Radiography. The AGO conservation department does not have a suitable instrument, and the conservation department at the nearby Royal Ontario Museum kindly offered use of their Faxitron, a cabinet X-Ray machine. The Faxitron is equipped with a relatively low kilovoltage and has a relatively small cabinet size. Developed for looking at tissue samples in operating theaters, it is particularly useful in the museum context for imaging small natural history and organic samples that fit in the cabinet and that are not particularly radio-opaque.

Time on the Faxitron was limited by practical factors: one workday was devoted to this project and thus determined the number of views of the prayer beads. Shot in the open position to reduce overlapping elements in the projections, each prayer bead was X-radiographed three times. All prayer beads were placed in the same three positions to provide projections from the anterior posterior, or front; the lateral or side; and at an oblique angle.

The X-ray images revealed many secrets about the prayer beads' construction (Fig. 5.6). Most surprising were the differences between the interior construction of the two skull beads. One of the skull's interiors is made up of stacked layers that contribute to the interior relief, while the other bead appears, though very similar at first glance, to have an entirely different construction. The interior has been carved from the frontal plane of the relief, out of the skull shaped mass of wood. Based on the X-radiography and subsequent study of associated works in other institutions, Suda identified the two skulls to be the work of ancillary workshops, supplying objects emulating the larger corpus of miniature boxwood carvings in response to a desire for and the dearth of miniature boxwood carvings [4].

Although the X-radiographs are extremely fine, they are two dimensional images of three dimensional objects. Thus, there is inevitably superimposition of some structures on others and subtleties of construction can be difficult to determine. While the Faxitron proved an excellent tool during the early investigation of the prayer beads, outstanding questions about the more complicated prayer beads' construction still remained.



**Fig. 5.6** Prayer beads AGO ID 29282 and 29283. X-Radiographs revealing different strategies in the carving of the inner reliefs

## 5.6 Micro CT Scanning

A prayer bead in the Rijksmuseum had been successfully imaged using synchrotron-based computer X-ray microtomography [5] and although the prayer beads in the Thomson Collection were also excellent candidates for this kind of imaging, there were a number of challenges. These included securing time at a synchrotron facility and consideration of the implicit risk involved in travelling with a large number of delicate artworks. Dr. Wallet, a senior scientist at the Rijksmuseum, kindly suggested considering micro-CT scanning as a lower resolution but adequate tool.

Micro-CT scanning, or high-resolution X-ray tomography, essentially produces the same output as medical computerized tomography or CT scanning, but it uses a different process and it produces images of considerably higher resolution. Both use computers to assemble X-radiographs taken from different angles of the subject being scanned into a 3D volume. The clinical scanner creates slices or cross-sections in the axial plane, which can be reformatted along different planes, or combined to create three-dimensional or volumetric models [6]. The micro-CT scanner takes many individual projections to calculate a volume using a back-projection algorithm [7], which can then be manipulated in many different ways, including producing slices like the clinical scanner. Both can produce 3D models that can be manipulated in virtual space.

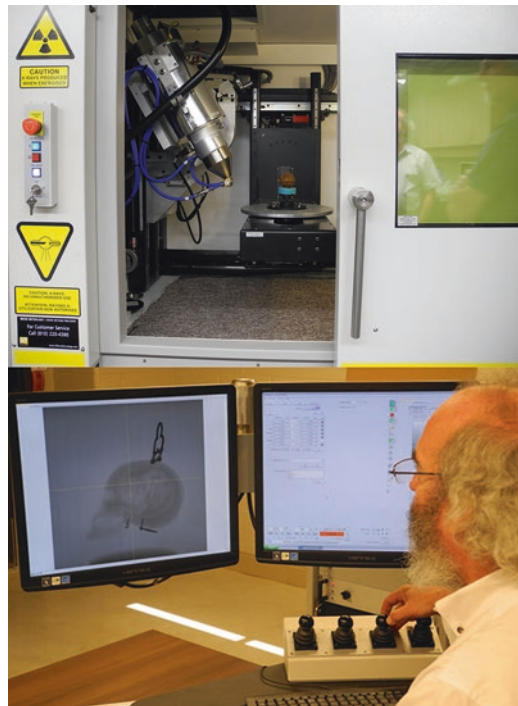
Micro-CT scanning refers specifically to scanners which can deliver output in which voxels (3D isometric pixels) size can be measured in the sub-100 micron range [6]. This is a relatively new technology and is made possible by the enormous

capacity of computer memory and the extremely fine mechanical engineering that enables such high-resolution capture and manipulation. Elliot and Dover [8] developed the first micro-CT system in the early 1980s to examine the structure of a shell, with units first becoming commercially available in the 1990s [9].

A number of different institutions and manufacturers were contacted in the search for a suitable instrument to study the AGO miniature boxwoods. It became apparent that limiting factors included chamber size and the environment within the chamber. Even though some machines were developed for *in vivo* examination of laboratory specimens such as rats, the comfort of the specimen was evidently not of primary concern, with high temperatures being produced by the hardware during the scanning process. The sudden increased temperature in the chambers of some of the instruments ruled out their use as the risk to the boxwood prayer beads would be too great. In addition, many *in vivo* scanners have very small bores, which are not large enough to accommodate the AGO's larger prayer beads or the miniature altarpieces.

Fortuitously, the search for a suitable scanner ended with an introduction to Dr. Andrew Nelson at the Sustainable Archaeology (SA) facility in the Department of Anthropology at Western University, in London, Ontario, approximately 200 km west of Toronto (<http://www.sustainablearchaeology.org/>) (Fig. 5.7). The SA houses a Nikon Metrology XT H 225 micro-tomographic (micro-CT) scanner, capable of scanning the beads at a minimum resolution of 37 micron voxels. The micro-CT

**Fig. 5.7** Prayer bead in micro CT scanner at Department of Sustainable Archaeology, Western University



scanner is used for non-invasive studies of archaeological and bioarchaeological materials (and now artworks) revealing a sample's internal structures and features. The scanner can investigate objects with a maximum volume close to that of a human head.

Most importantly for the purposes of this study, the environment in the imaging chamber, which is sizable, contains a cooling system, and so is not subjected to high temperatures and corresponding reductions in relative humidity. The HOBO U12 Temp/RH/Light/External Data Logger (Onset Computer Corporation) was used to record the chamber's environment to ensure that conditions therein were stable and would not damage these sensitive artworks. Over a test period of 10 h, the data logger showed a slight increase in temperature from approximately 22–24 °C with a corresponding decrease in relative humidity from approximately 50% to 46%.

The scans were initially read and manipulated at the SA with licensed software, Volume Graphics, VGStudio Max 2.2. For further processing, the data was exported in industry standard DICOM format so that it could be read using free downloaded software called ImageJ, which was initially used on site at the AGO to manipulate the images. Subsequently, an Advanced 3D Analysis software, ORS Visual SI, developed by Object Research Systems, (<http://theobjects.com>), was used at the AGO to manipulate the datasets: segmentation tools were used to virtually dissect the prayer beads and miniature altarpieces into their composite pieces. Exported files capturing only the surface morphology in “meshes” were used by Priam Givord to create the creation of “Small Wonders: the Virtual Reality Experience” a co-production between the AGO, the Canadian Film Centre Media Lab and Seneca College (Fig. 5.8).

The value of the micro-CT scans and corresponding digital assets was immediately recognized. Scrolling through successive slices of the volume captured in the dataset clearly revealed the construction secrets of these superlative carvings. Joining techniques including tongue and groove, rabbets and butt joints secured with pegs became visible. The problems associated with overlapping elements in the X-radiographs were no longer an issue at all.

The imaging technique provided unequivocal answers and was instrumental in solving a small but significant mystery concerning one of the collection's skull shaped prayer beads. The carved hasp of the bead became of special interest after Suda, along with a former colleague at the MET, re attributed its heraldic device carved in relief to Albrecht of Mainz, Archbishop of Mainz and Magdeburg from 1513–1545. This led to questions surrounding the production of the bead: had it been commissioned specifically for Albrecht, or perhaps the hasp had been added later, after the bead was already complete? While X-radiographs of this area were difficult to interpret, the micro CT scans show that without a doubt, the clasp with the attribution to Albrecht was added after the prayer bead had already been made (Fig. 5.9).



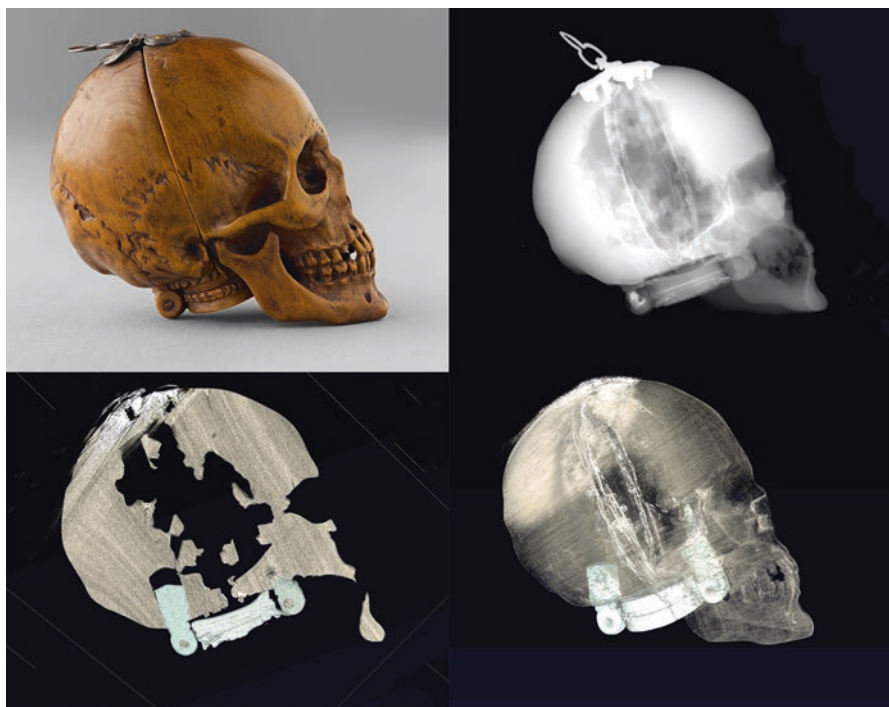
**Fig. 5.8** Scene of a visitor in the “Small Wonders: the VR Experience” at the AGO. The screen in the background repeats the user’s view

## 5.7 Scientific Analysis

In order to understand the original manufacture and subsequent repairs and restorations to the prayer beads, minute samples of adhesives, coatings and polychrome decoration were analysed. Elizabeth Moffatt and Jennifer Poulin at the Canadian Conservation Institute, undertook this analysis using a variety of scientific instrumentation, including: Fourier transform infrared spectroscopy (FTIR); scanning electron microscopy-energy dispersive spectrometry (SEM-EDS); thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS); and Raman spectroscopy.

The following coatings have been identified: shellac, beeswax, pine resin, and a labdane resin. Adhesives may eventually help link a prayer bead to a specific restorer or school of restoration, or be used to date a restoration. Animal glue, a typical wood adhesive, has been found, along with the much more modern poly(vinyl acetate), and even a polyester resin.

A remarkable aspect of these wooden art objects is an overall lack of polychromy. It seems that the prayer beads were intended to show off their maker’s virtuosic skill in carving and joining elements and so were left bare of gesso and paint. There are, however, some notable exceptions to this. One of the more complex Thomson prayer beads, AGO ID number 29365, has a polychromed passage under a ledge, in an area depicting hell (Fig. 5.10). The painted areas here are subtle and mostly hidden from view: a red paint is used to embellish carved flames and a dark bluish



**Fig. 5.9** Prayer bead AGO ID 29282. Upper left, photograph; upper right, X-radiograph; lower left, micro-CT slice showing insertion of pegs in skull; lower right, rendering created using ORS Advanced 3D Analysis software and micro-CT scan, the hasp and pegs are visible in situ as the density of the rest of the object has been reduced visually

black pigment coats the interior walls of the cavern like area. Traces of these two paints were identified by the Canadian Conservation Institute (CCI) as a carbon-based black pigment with a protein binding medium and a red paint consisting of a mixture of a red lake, gypsum and a protein. The red pigment's organic colorant was characterized using TD-GC-MS as a compound extracted from kermes. A protein derived from wool found in the red pigment suggests that it was extracted from a dyed wooden textile, a practice associated with the production of pigments used in medieval manuscript illuminations [10]. The use of polychromy in this prayer bead links it convincingly to a prayer bead found in the collection of the British Museum's Waddeson Bequest [11].

## 5.8 Conclusion

The technical study of the AGO's Thomson Collection of Gothic miniature boxwoods has been a resounding success, underscoring the fortuitous intersection of recent advances in technology and the authors' ambition to uncover the mysterious



**Fig. 5.10** Prayer bead AGO ID 29365, has a polychromed passage where a red paint is used to embellish carved flames and a dark bluish black pigment coats the interior walls of the cavern like area

construction of these objects. The challenges these works present to modern analysts is a tribute to those who produced them. Macro photography, X-radiography and micro-CT scanning were all necessary to deconstruct these tiny objects, with the latter ultimately being the decisive tool in fully understanding their construction. The scientific analysis of coatings, paints and adhesives was also essential in creating a full picture of the objects, not only of their manufacture, but also giving insight into each object's history of use and restoration. The array of high-technology deployed for this study, and the details it revealed about their construction also causes us to reflect on the remarkable skills of the medieval artisans who made these beads with the simplest of tools and only primitive crystal lenses for magnification.

While at first proving more challenging than originally anticipated, the technical study of the prayer beads prompted partnerships with several organizations in order to gain access to cutting edge technologies and expert knowledge. The AGO's new connections to the Departments of Chemistry and Anthropology at the University of Western Ontario and renewed connections with our other partners, have proven not only informative, but inspiring for future collaborative ventures.

The value of the work described in this paper is corroborated by the exhibition "Small Wonders" and its overwhelmingly positive reception. The discovery and sharing of the Gothic miniature boxwood carvings' secrets using dramatically magnified images of the works, computer animations and the Virtual Reality experience did not detract from their former seductive mystery, as some feared, but rather made them even more intriguing to a wider range of audiences.

**Acknowledgments** For their support of the technical work carried out on the Thomson Collection, the authors would like to acknowledge the extraordinary support of the AGO, and in particular, Maria Sullivan, Angela Glover, Wendy Hebditch and Margaret Haupt of the Art Gallery of Ontario and Annick Lapotre and David Franklin of TWAL. The online catalogue raisonné and digital photography campaign was made possible through the generous support of Thomson Works of Art. We would also like to acknowledge the dedicated staff and support of the Sustainable Archaeology facility, particularly Zoe Morris and Rhonda Bathurst, at the University of Western Ontario and the staff at ORS, in particular Eric Fournier. Further thanks are owed to exhibition partners at the Metropolitan Museum of Art and the Rijksmuseum as well as the support of the Canadian Film Centre's Media Lab and Seneca College for the development and distribution of "Small Wonders: the VR Experience."

## References

1. Boehm B. P. Dandridge, L. Ellis and A. Suda. 2016. *Small Wonders: Gothic Boxwood Miniatures*, eds. L. Ellis and A. Suda. Toronto: AGO Research.
2. Scholten, F. Ed. *Small Wonders: Late-Gothic Boxwood Micro-Carvings from the Low Countries*, 514–573. Amsterdam: Rijksmuseum Publications Department.
3. Ellis L. A. Suda, R.M. Martin, E. Moffatt, J. Poulin, and A. Nelson. 2017. The Virtual Deconstruction of a Prayer Bead in the Thomson Collection at the Art Gallery of Ontario with Micro-CT Scanning and Advanced 3D Analysis Software. In *Prayer-Nuts, Private Devotion and Early Modern Art Collecting*, 22. Abegg-Stiftung eds. E. Wetter and F. Scholten, 208–217, Riggisber: Riggisberger Berichte.
4. Suda A. (2017) Sixteenth-Century Micro-Carving and Exceptions to the Norm: Three Case Studies. In: *Prayer-Nuts, Private Devotion and Early Modern Art Collecting*, Riggisberger Berichte 22: 186–207, E. Wetter and F. Scholten F (eds), Riggisber: Abegg-Stiftung.
5. Peter Reischig, Jorik Blaas, Charl Botha, Alberto Bravin, Liisa Porra, Christian Nemoz, Arie Wallert, Joris Dik, (2009) A note on medieval microfabrication: the visualization of a prayer nut by synchrotron-based computer X-ray tomography. *Journal of Synchrotron Radiation* 16 (2):310-313
6. Kalender, W.A. 2011. *Computed Tomography. Fundamentals, System Technology, Image Quality, Applications*. Erlangen: Publicis Publishing.
7. Holdsworth D.W. and M.M. Thorton. 2002. Micro-CT in small animal and specimen imaging. *Trends in Biotechnology* 20: S34–S39.
8. Elliott, J.C. and S.D. Dover. 1982. X-ray microtomography. *Journal of Microscopy* 126 (2): 11–213.
9. Elliott, J.C. G. Davis and S. D. Dover. 2008. X-ray microtomography, past and present. In *Developments in X-Ray Tomography VI*, ed. S.R. Stock Proc. of SPIE 7078 (707803): 0277–786.
10. Moffatt E. and J. Poulin. 2012. *Analysis of Coatings on Prayer Beads in the Thomson Collection, Part I*, for the Art Gallery of Ontario. CCI Report No. CSD 4971.1, CCI 123806
11. Suda A., and L. Ellis . 2012. *Curator's Project: Investigating Miniature Boxwood Carving at the Art Gallery of Ontario in Toronto*. Codart EZine. 2 Spring 2013. <http://ezine.codart.nl/17/issue/45/artikel/investigating-miniature-boxwood-carving-at-the-art-gallery-of-ontario-in-toronto/?id=119>. Accessed: 30/03/2019.