Journal of
Synchrotron Radiation
ISSN 0909-0495

Received 13 October 2008
Accepted 17 December 2008

A note on medieval microfabrication: the visualization of a prayer nut by synchrotron-based computer X-ray tomography

Peter Reischig,[a,b] Jorik Blaas,[a] Charl Botha,[a] Alberto Bravin,[c] Liisa Porra,[c] Christian Nemoz,[c] Arie Wallert[b] and Joris Dik[a]*

[a]Delft University of Technology, Delft, The Netherlands, [b]Rijksmuseum, Amsterdam, The Netherlands, and [c]European Synchrotron Radiation Facility (ESRF), Grenoble, France. E-mail: j.dik@tudelft.nl

One of the most fascinating objects in the Rijksmuseum (Amsterdam, The Netherlands) is an early 16th century prayer nut. This spherical wooden object measures 4 cm in diameter and consists of two hemispheres connected with a small hinge so that it can be opened. The interior of the nut holds wood carvings with scenes from the life of Christ. These miniature reliefs show an incredible degree of finish with carving details well beyond the millimetre scale. In the present paper it is shown how synchrotron-based computer X-ray tomography revealed the structure and fabrication method of the bead. The central part of the relief was cut from a single piece of wood, rather than assembled from multiple components, underlining the extraordinary manual dexterity of its maker. In addition, a piece of fibrous material contained in the inner structure of the bead is revealed. This may have served as a carrier for an odorous compound, which would be in line with the religious function of the prayer nut.

Keywords: X-ray tomography; tomography reconstruction; cultural heritage; prayer nut; wood.

1. Introduction

In medieval Europe religion was an omnipresent aspect in daily life. The 15th century showed a strong tendency towards private worship. The Christian worshipper tried to empathize with Christ by privately meditating on His sufferings. All kinds of attributes, usually with depictions of Christ's passion, were used as support during prayer and meditation. A common example is the traditional rosary, a string of beads for counting when engaged in repetitive prayers (Winston-Mien, 1997). Prayer nuts were sometimes attached to such rosaries. These prayer nuts are a much more precious and luxurious type of prayer item or devotionalia. Prayer nuts consist of two hemispheres connected with a hinge and a catch, so that it can be opened during prayer. The interior is decorated with refined wood carving of biblical scenes. Their miniature format nicely reflects the personal and intimate character of 15th century religious life (Falkenburg & Scholten, 1999).

The Rijksmuseum in Amsterdam owns a beautifully preserved prayer nut from the early 16th century (Fig. 1). The nut is made of boxwood and measures 4 cm in diameter. The outer part of the hemispheres is decorated with a complex pattern with a Gothic motif, while the interior shows the crucifixion and Christ carrying the cross. Around the edge of both scenes one can read two Latin inscriptions, commemorating the redemption through Christ. The scenes have been carved with an exuberant virtuosity and an amazing attention to detail. On a few cm^2 the artist succeeded in recreating the crucifixion of Christ with no less than 13 figures, three crosses, five horses and two pikes. Despite this crowd, however, the illusion of depth in the relief is very convincing. This is partly achieved by upscaling the figures in the front and downscaling the figures in the back. In addition, the scene is staged in three consecutive planes. In the front we see various lamenting bystanders, behind them a line of horsemen, partially viewed on their back, while the third plane shows again a frontal view on the crucified figures. This sequence adds to the spatial illusion, but also raises the question of how this miniaturized three-

Figure 1
Boxwood prayer nut with Christ carrying the cross and the crucifixion, c. 1515, Rijksmuseum, Amsterdam, The Netherlands.

dimensional puzzle was made. Given the ingenious construction of the illusionary space with its multiple planes and figures, would the actual making of the object also depend on the assembly of different components? Would such components be carved piece by piece, then assembled and finally integrated in the nut? In order to answer these questions we decided to perform an X-ray tomography experiment of the prayer nut shown in Fig. 1. Our aim was to (i) obtain an overview of the inner structure of the bead and (ii) hopefully shed light on the construction of this delicate piece of late-medieval microfabrication.

2. Methods and techniques

Tomographic images of the bead were recorded using monochromatic X-rays available at the ID17 biomedical beamline of the European Synchrotron Radiation Facility (Grenoble, France). The set-up is described elsewhere in detail (Fiedler *et al.*, 2004; Nemoz *et al.*, 2007). Briefly, the source of synchrotron radiation at ID17 is a symmetrical multipole wiggler using a 70 mm gap. The fixed-exit two-crystal Si(111) monochromator in Laue (transmission) geometry is located at a distance of 141.5 m from the source (Suortti *et al.*, 2000). The beam energy E was 30 keV. The bandwidth of the monochromatic beam was $\Delta E/E \simeq 5 \times 10^{-4}$ in this setting. The sample is placed 10 m downstream from the monochromator on an optical table, and it can be rotated in the fan beam about a vertical axis for computed tomography imaging. The distance between the sample and the detector was 2.5 m. A scheme of the set-up is shown by Fiedler *et al.* (2004). The high-resolution detector used in this study is called a FReLoN CCD camera (Bravin *et al.*, 2003). It has an active input surface of 94 $\times$ 94 mm, where the incoming X-rays are converted by a 100 µm-thick standard mammographic phosphor screen (Gd2O2S:Tb, 5 g cm^{-3} density) to visible light, which is then guided by tapered fibre optics onto the CCD array of 2048 $\times$ 2048 pixels. By this reduction an effective pixel size of 47 $\times$ 47 µm is achieved, and the resolution is about 10 lines mm^{-1} at the 5% level of the modulation transfer function. The detective quantum efficiency is 0.3 at 33 keV and zero frequency (Coan *et al.*, 2006). The height of the beam is 0.7 mm so that on the detector only a few horizontal lines are illuminated. For obtaining each tomographic slice, 1440 projections at 0.25 degree interval are recorded; after flat-field normalization, images are reconstructed using a standard filtered back-projection algorithm (Hamming filter).

The reconstruction of the top half of the object resulted in 667 slices, each of resolution 1133 (fixme) pixels squared. The *unu* utility, part of the *TEEM*[1] software toolkit, was used to convert the reconstructed slices to a single volume data set of 3.2 Gbytes. The reconstructed slices form a volume describing the densities of the prayer nut in a rectangular grid of discrete positions. To facilitate further processing of the data volume, the values were quantized to an 8-bit form, reducing the volume size to 816 Mbytes, which allowed it to fit into the RAM of our workstation. We also used the *unu* utility to create multi-planar reconstructions (MPRs), *i.e.* interpolated slices of arbitrary orientation through the volume. The MPRs can be used to inspect details of the interior structure. We made use of the *Miter* direct volume rendering software, also part of the *TEEM* toolkit, along with our own enhancements, to create interactive three-dimensional renderings of the prayer nut. The volume renderer was set up to show a single surface layer, representing the boundary between wood and air. For this, a threshold density value was chosen based on a histogram of all density values in the volume data set. The

[1] http://teem.sourceforge.net/.

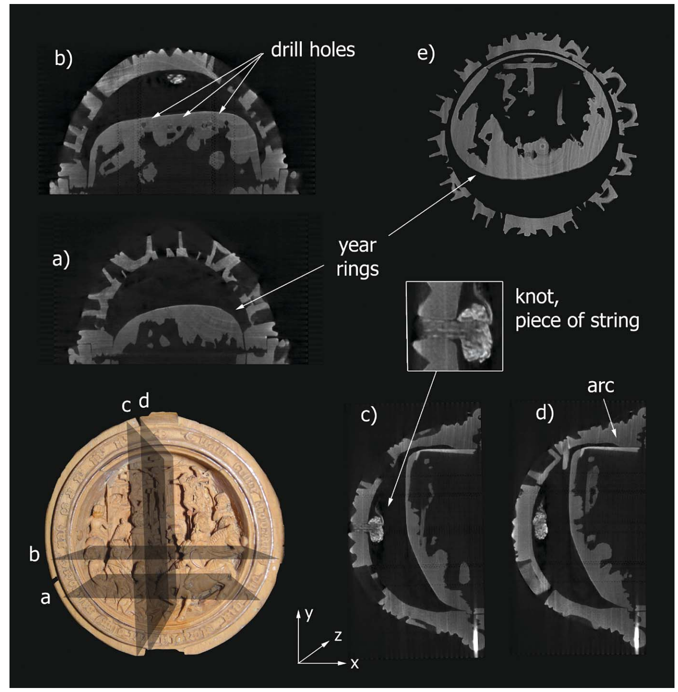

Figure 2
Sections through all three axes of the prayer nut; the approximate position of the sections is indicated in translucence. Section (e) runs parallel to the plane of view in the photograph and is therefore not indicated.

volume renderings were used to obtain a more high-level overview of the characteristics of the nut and to identify interesting features. Based on this localization, the MPRs were used to zoom in on and to study the identified positions. The volume renderings were also more suitable for showing surface details. Finally, we produced cut-away views to expose the internal structure of the object in context.

3. Results

Fig. 2 shows different two-dimensional sections along three axes through the prayer bead. The corresponding planes are indicated in translucence in the photograph, except for the section parallel to the plane of view (e). Fig. 3 contains volume reconstructions projected at different angles to enhance the perception of depth. The upper row shows the inside of the bead with a vertical cut, so that some features from Fig. 2 are included. The lower line shows the outer decoration of the bead. Video animations of both reconstructions are included in the digital depository of this journal.[2]

4. Discussion and conclusion

The sections in Fig. 2 reveal the shell structure of the bead. The object consists of an outer hemisphere into which the inner wood carving has been placed. Both parts are joined with two pins on the left and right (not visualized). The back of the inner part is held in position by a small pin [see section (d)]. Note that the relief has been cut from a single piece. No interfaces could be detected that would indicate some form of joining. Instead, the relief shows a continuous pattern of year rings [(a) and (e)], which also applies to the outer shell. We

[2] Supplementary data for this paper are available from the IUCr electronic archives (Reference: GF5017). Services for accessing these data are described at the back of the journal.

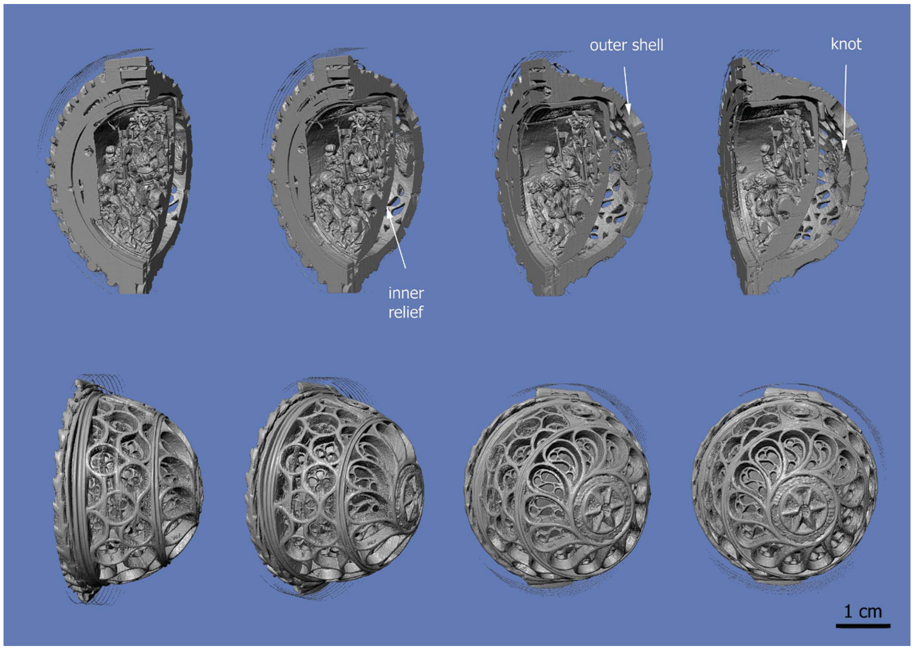

Figure 3
Upper row: volume reconstructions with a vertical cut through the middle of the nut, revealing the shell structure as well as the knot sandwiched between the outer and inner shells. Note the openings in the outer shell. Lower row: volume reconstruction of the outer shell with Gothic motif.

only noted two types of additions to the relief. First, the crosses and pikes have been cut separately and were then added. A horizontal section through the middle of the relief shows submillimetre drill holes into which the crosses were placed (*b*). Furthermore, the upper section of the relief, *i.e.* the arc above the crucifixion scene, has been cut from another separate piece of wood. This was already noticed by visual inspection (Fig. 1), but also becomes clear from cross sections (*c*) and (*d*), where we notice the joints and a slightly increased absorbance of this separate component. Thus, the relief has been composed from four major parts: the outside shell with its Gothic pattern, the inside relief of the crucifixion, smaller details like the crosses and pikes, and finally the arc above the crucifixion scene. The latter was taken away in order to have a large angle access to the relief. This is necessary to carve figures with undercuts and to drill holes from above.

Unfortunately, there are not many contemporary sources on the production of prayer nuts. We do know that the making of rosaries was a specialized craft in 15th century Europe with major production centres in Southern Germany and Flanders (Winston-Mien, 1997). These craftsmen were called paternosters, referring to the repetitive prayer of ‘Our Father’, for which rosaries were used. Fig. 4 shows such a paternoster at work. We see how a hollow semicircular drill is placed on a wooden block in order to prepare multiple hemispheres. The same block of wood would then be worked in an identical manner from the back in order to create perfect orbs. A larger globule would have been made for the prayer nut, which was then cut in half and both sections were then hollowed out. The outer decoration and the inner relief would have been made with an array of small drills, chisels and knives. We suspect that the artist must have used some form of optical magnification for the micro-carving, probably a lens, which would have been available in the early 16th century.

In between the inner and outer shell we notice a rather small compartment in the tomography sections [Fig. 2, (*a*)–(*d*)]. Note how the outer casing has an open structure with numerous holes. The top of the outer hemisphere also shows a hole, inside which a woven rope-like structure can be seen with a thick knot in the bead’s interior. The disentangled strings at the end indicate the fibrous nature of the material. It is suspected that the string, which has broken off inside the drill hole, was originally used to attach the bead, *e.g.* to a rosary. The knot remains hidden from the outside and cannot be seen through the cavities of the outer shell, as shown in the three-dimensional volume reconstruction of the sectioned bead.

Given the open structure of the casing, the fibrous material of the rather large knot may have also served another purpose. It has been suggested that fragrances were sometimes enclosed in prayer nuts (Falkenburg & Scholten, 1999). Also, in this case, the object may have served as a so-called pomander casing. Pomanders were generally made by softening resinous substances and mixing them together, often with dirt or clay, or wax. These pomanders were often carried in open boxwood cases, with piercings, or carvings to let the scent out. Some pomander cases even had sections for several different scents of pomanders, as well as compartments for a sponge soaked in aromatic vinegars. In a more modest form, simple pierced cases or

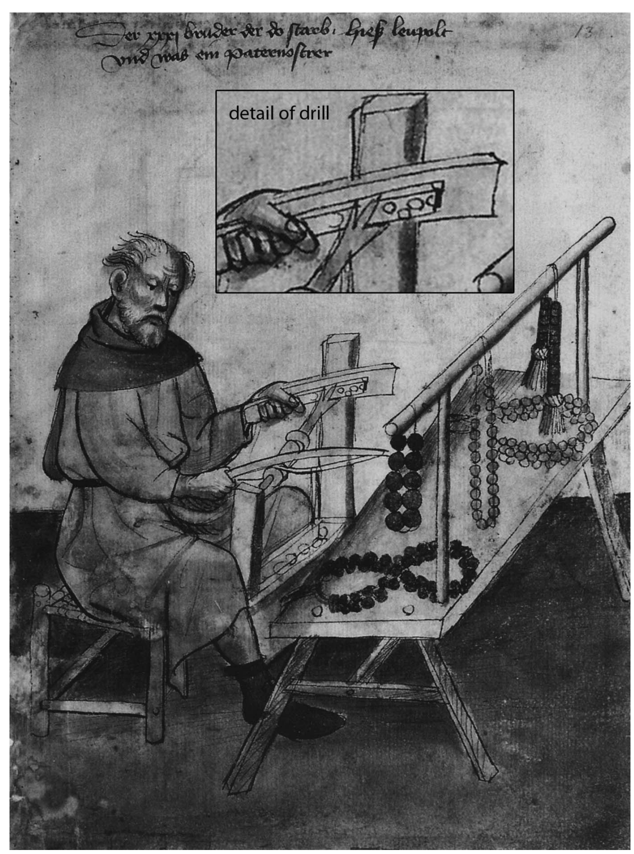

Figure 4
Contemporary medieval depiction of the production of prayer beads, Hausbuch (Amb. 317. 2°, fol. 13r), Stadtbibliothek, Nuremberg, Germany,

just hollowed-out fruit were stuffed with herbs and spices (Clarkson, 1939). The presence of these odiferous substances would literally increase the spiritual experience of the worshipper during prayer. The fibrous material of the knot may have been the carrier for such odorous compounds that would have been released through the open structure of the outer shell. Pending further analysis, this suggestion could not be corroborated.

However that may be, this examination has shown that synchrotron-based X-ray tomography can be applied successfully to study the fabrication methods of medieval prayer nuts in a non-destructive manner. It would therefore be worthwhile to examine more of such objects and eventually determine developments in manufacturing and compare prayer nuts from different workshops.

We would like to thank Robert van Langh and Frits Scholten from the Rijksmuseum in Amsterdam for their support of this project.

References

Bravin, A., Fiedler, S., Coan, P., Labiche, J. C., Ponchut, C., Peterzol, A. & Thomlinson, W. (2003). *Nucl. Instrum. Methods Phys. Res. A*, **510**, 35–40.

Clarkson, R. (1939). *Magic Gardens: A Modern Chronicle of Herbs and Savory Seeds.* New York: Macmillan.

Coan, P., Peterzol, A., Fiedler, S., Ponchut, C., Labiche, J. C. & Bravin, A. (2006). *J. Synchrotron Rad.* **13**, 260–270.

Falkenburg, R. L. & Scholten, F. (1999). *A Sense of Heaven: 16th Century Boxwood Carvings for Private Devotion.* Leeds: Henry Moore Institute.

Fiedler, S., Bravin, A., Keyriläinen, J., Fernández, M., Suortti, P., Thomlinson, W., Tenhunen, M., Virkkunen, P. & Karjalainen-Lindsberg, M. L. (2004). *Phys. Med. Biol.* **49**, 175–188.

Nemoz, C. *et al.* (2007). *AIP Conf. Proc.* **879**, 1887–1890.

Suortti, P., Fiedler, S., Bravin, A., Brochard, T., Mattenet, M., Renier, M., Spanne, P., Thomlinson, W., Charvet, A. M., Elleaume, H., Schulze-Briese, C. & Thompson, A. C. (2000). *J. Synchrotron Rad.* **7**, 340–347.

Winston-Mien, A. (1997). *Stories of the Rose: The Making of the Rosary in the Middle Ages.* University Park: Penn State Press.