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title: Case Study 2

subtitle: Exquisite Objects, Prodigious Technique: Aquamanilia, Vessels of the European Middle Ages

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bio: Pete Dandridge (Conservator Emeritus, Metropolitan Museum of Art, New York) came to the Metropolitan Museum in 1979 from the Cooperstown Graduate Program. He was principal conservator of the ivories, enamels, and metalwork in the Department of Medieval Art and The Cloisters with a focus on the technical history of those materials and the capabilities of the associated artists. He contributed to *Small Wonders: Late-Gothic Boxwood Micro-Carvings from the Low Countries* (2016) and was an author and coeditor for both *Medieval Copper, Bronze and Brass* (2013) and the exhibition *Lions, Dragons, and Other Beasts: Aquamanilia of the Middle Ages, Vessels for Church and Table* (2006); he also co-curated the latter.

abstract: The collection of aquamanilia and associated medieval German metalwork in New York’s Metropolitan Museum of Art became the focus of an exhibition that integrated art historical analyses with technical examinations of the vessels in the Met’s collections and related cast objects in other collections around the world. Invaluable insights were also gleaned from the experimental replication of one of the Met’s lion aquamanilia that followed closely the processes prescribed by the medieval monk Theophilus in his twelfth-century treatise *On Divers Arts: The Foremost Medieval Treatise on Painting, Glassmaking, and Metalwork*.

short\_title: Case Study 2

## Slide 1: Introduction

Aquamanilia are zoomorphic or anthropomorphic vessels for the washing of hands at the table. %%Cast%% from copper alloys, they emerged as a distinct artistic form in the twelfth century in Lower Saxony and continued to be fabricated in various areas of Germany for the next three centuries. They were filled via lidded openings, generally at the tops of the animal’s or rider’s head, with the spouts either integrally cast as part of the figure’s mouth or separately fabricated as a spigot and mechanically set into its chest. They represent an important stage in the evolution of European casting technology, being the first hollow, fully three-dimensional sculptural forms produced since antiquity. More than three hundred aquamanilia are known to have survived through the centuries, some inspiring nineteenth-century %%replicas%%, and all are unique.

**Figs. 469, 470, 471**

## Slide 2: Context for the technical study

The collection of aquamanilia and associated medieval German metalwork in New York’s Metropolitan Museum of Art became the focus of an exhibition that integrated art historical analyses with technical examinations of the vessels in the Met’s collections and related cast objects in other collections around the world. Several dozen works formed the focal point of this study, though information from many others also fed into the research. Invaluable insights were also gleaned from the experimental replication of one of the Met’s lion aquamanilia that followed closely the processes prescribed by the medieval monk Theophilus in his twelfth-century treatise *On Divers Arts: The Foremost Medieval Treatise on Painting, Glassmaking, and Metalwork*. Written around the time when aquamanilia first appeared, the treatise describes, among other things, the casting of a complex sculptural censer—a hollow, copper-alloy object.

**Figs. 469, 472**

## Slide 3: The mane questions (pardon the pun)

• How were these fantastical objects fabricated?

• How does their facture compare to the processes outlined in Theophilus’s twelfth-century treatise? Might those descriptions help in the interpretation of the technical evidence preserved in the vessels? Do they apply to the fabrication of aquamanilia as well?

• Ultimately, with data from a large enough sampling pool, would it be possible to start tracing the evolution of this casting technology as the centers of production shifted over time?

• Might it be possible to establish idiosyncratic patterns in techniques or materials that would help to identify and characterize the products of particular workshops or regional production centers?

This case study focuses predominantly on the first two questions.

**Fig. 470**

## Slide 4: Lost-wax casting

All technical evidence points to medieval aquamanilia being cast by the %%lost-wax%% process. This basically entails fashioning a %%model%% of the desired form in wax with which to create a hollow impression in a fire-resistant %%mold%% material that will serve as a matrix for the liquefied metal. The uniqueness of each known example suggests that aquamanilia were directly modeled over earthen %%cores%%. The internal surfaces are all relatively smooth, and there are no waxy drip marks or other physical indicators that they were formed by an indirect process.

**Video 5**

## Slide 5: Fabrication: The core (replication)

The internal volume of any hollow %%bronze%% is defined by a core made of fire-resistant material. Theophilus describes shaping a well-kneaded and sifted mixture of sandy clay and dried dung into more or less the desired form, integrating many of its physical features. The sand would temper the clay, reducing %%shrinkage%% and cracking during firing. The organic material would provide “green” strength or cohesiveness to the mixture and create a more porous body that could help absorb any vapors that might evolve during the %%pour%%. An internal %%armature%% would help to support the weight of the clay, and evidence for the same was found in the larger and more complex structures. After casting, the core material and armature were generally removed to clear the hollow of the vessel for use.

**Figs. 473, 474, video 4**

## Slide 6: Fabrication: The core (examination)

Traces of the earthen mixture preserved in harder-to-access areas of several of the aquamanilia were sampled and prepared as thin sections for petrographic analysis and scanning electron microscope (SEM) imaging to characterize their material makeup. Several examples included the identifiable forms of organic inclusions. The mineral content pointed to a metamorphic rock source, but overall these analyses were (as yet) inconclusive regarding the identification of the clays’ geological origin, and therefore the geographical location of the aquamanilia’s production.

**Fig. 475**

## Slide 7: Fabrication: Wax layer (replication)

The model for the censer Theophilus describes was created by first overlaying the cured core with pieces of sheet wax rolled out to a specific depth, cut into “small pieces according to the spaces which you have cut in the clay of the censer.” These were warmed and applied with the aid of a hot iron, then trimmed and smoothed out, taking care that the thickness of the wax layer was “not thicker or thinner in one place than another.” Such evenness helps to ensure that the metal cools and shrinks at an even rate, avoiding distortions. The fine modeling of details can then begin. This same process was applied to the replication of the Lion aquamanile.

**Figs. 472, 476, video 5**

## Slide 8: Fabrication: Wax model (examination 1)

The physical evidence points to the aquamanile being directly modeled in wax as described by the monk. The many fine details have the quality of a malleable material, and many were ultimately added in the wax sheet. In some instances, elements such as the sculptural handles would have been formed separately and then joined to the body of the vessel.

Radiographs were invaluable in assessing the overall form of the aquamanile’s core and how the wax layer (translated into metal) was built up. In such images, the denser, more X-ray-opaque materials show up whiter. The consistent opacity observed in the central part of both lions’ bodies points to their modeling in a single layer of sheet wax. The slimmer parts of the legs were modeled in solid wax.

In the X-ray of the lion on the left, the details of the mane are denser, showing that they were built up with additional triangles of wax. The undulating shapes of the mane in the lion on the right, in contrast, were already formed in the core and overlaid by an even layer of wax as prescribed. The darker areas in this second lion’s mane may have occurred while pressing the wax sheet onto the more complex core shapes, or from revisions in the final modeling that might have thinned the wax and resultant metal %%cast%%.

**Figs. 477, 478**

## Slide 9: Fabrication: Wax model (examination 2)

The more complex and larger aquamanilia required a more sophisticated structure, which could signify separately modeled figures (and cores) and/or the additional support of localized armatures. The retained core of the falconer, for instance, appears from the radiographs to be continuous with that of the horse. The slightly darker shape in the hollow suggests that it preserves the less-dense impression left by an organic armature. Conversely, the X-ray image of the small Samson wrestling on the back of the lion shows that the core of the human figurine extended only to his knees and shoulders. Samson was modeled in wax separately before being joined to the back of the wax lion. A fine wire armature can be detected coming down from his neck to his belly area.

Theophilus does not refer to armatures as the openwork form of the censer, and the bell-like shape of its two halves provided sufficient surface area for contact between the core and the %%investment%% to not require the use of armatures, but fine wires and other materials were certainly used in more complex objects. Again, these were often removed from the body of the vessel after casting, but were left in other areas.

**Figs. 479, 480, 481, 482**

## Slide 10: Fabrication: Core pins, sprueing, and investing (replication)

Once the modeling was complete, metal %%core pins%%were partiallyinserted through the wax and into the core to secure the registration of the aquamanile’s core within its outer mold or investment (see **video 5**). Next, the model would be fitted with a network of %%sprues%% through which to melt out the wax, feed the liquefied metal in the mold, and allow the gas and air to escape. When possible, connections helping with that flow were integrated into the design of the sculptural form itself, as can be seen in the falconer.

Then, as Theophilus describes, multiple layers of earthen mold material (similar to that of the core) were gradually built up over the sprued wax model. This clay investment mold containing the sprued model would be heated to melt out the wax, which, being an expensive material, would according to the treatise be recovered and presumably recycled. Heating the mold would also serve to get rid of all moisture because, the monk warns, “if the inside cores experience dampness, they immediately swell and all your work will break apart.” The mold is then heated until it is red hot and buried in a pit, casting cup up, ready to receive the liquefied metal, which is poured from a crucible in which it has, meanwhile, been alloyed.

**Figs. 483, 484, video 8**

## Slide 11: Fabrication: Core pins and core plugs (examination)

Examination of the aquamanilia revealed that these were made of copper or iron, and some out of bent copper sheet. The use of one type did not preclude the other. Should the core pins fuse to the metal during casting, they were cut down to the level of the outer surface and smoothed over with some surrounding metal. But the internal portion is often still preserved on the inside, and visible in radiographs or in accessible areas. If it could be loosened, however, the core pin was removed and the resulting hole filled with a %%plug%%, which was often a tapered, hammered-in copper pin.

Patterns may be found in the treatment of core pins and may prove characteristic of a particular workshop. In the Nuremberg aquamanilia studied here, all core pins were removed, the ensuing holes rounded with files and plugged with shallow discs of metal similar to the cast (probably cut from a sprue), and their joins secured with %%soldering%%.

**Figs. 180, 485, 486, 487, 488**

## Slide 12: Metal

Theophilus describes coloring copper by the cementation process using “a stone of yellowish color, sometimes reddish.” This stone was, in fact, the zinc ore calamine and the process that of alloying “latten,” a brassy metal containing zinc as the primary alloying agent and tin and lead in levels above 1%. (Zinc as a metal had not yet been isolated or identified in his time.) This is the golden-colored metal predominantly used for aquamanilia. Workshops in northern Germany and Lower Saxony, and later in Nuremburg, were close to the source of these raw materials.

Each ore source has distinctive trace minerals that can help identify where the metal comes from. To what extent the tin and lead contents were intentional cannot be readily determined, as both were also contained in copper ores. And given that metals were often recycled, with each remelting, the zinc concentration might be reduced due to the evaporation of zinc vapor. With so many variables to consider and a relatively small statistical group to work from, the results thus far of the metal analysis are far from conclusive.

That said, over the span of production of aquamanilia, the techniques used to alloy the calamine with copper became more sophisticated, which allowed for an enhanced absorption of zinc. Such an increase can be seen in the alloy analysis of aquamanilia produced in Nuremberg at the beginning of the fifteenth century compared to earlier casts.

**Fig.** **489**

## Slide 13: Fabrication: Fettling

Once the metal had cooled in the mold, the investment was broken away to reveal the casting. %%Fettling%% was the initial step in finishing the raw casting with the retained sprueing system (runners and risers) and core pins cut back with %%chisels%% and files. Once these features were removed, the artist had greater access to the %%as-cast surface%%,which in medieval western Europe was generally coarse and required significant finishing. One can get a better sense of this in areas inaccessible to tooling, like the undersides of handles, or animals’ indented paws or hooves.

**Figs. 104, 277**

## Slide 14: Fabrication: Cast-in repairs

Imperfections and casting flaws seem to have been an anticipated outcome for medieval metalworkers. And the replication experiment ended up with a few as well. Theophilus suggests using a localized lost-wax casting process for making repairs. “If there is any flaw, due to neglect or accident, . . . thin out that place by filing around it. Apply wax and likewise add clay on top and when it is dry, heat it, and so pour over it until the liquid bronze flows into that place and what you have poured on top adheres. If, when you examine it, it is not strong enough, solder with burnt wine-tone and the filings of mixed silver and copper as we have described above.”

Many of the aquamanilia show evidence of such cast-in repairs. The metal-to-metal join lines are generally faint on the outer surface, but the denser masses of metal that flowed into the hollowed core area are clearly defined in the X-rays.

**Figs. 180, 490, 491**

## Slide 15: Fabrication: Patches and plugs

Hammered-in copper-alloy plugs or %%patches%% were used on smaller flaws with no evidence of solder reinforcement. Such reinforcement is, however, apparent in aquamanilia cast in Nuremberg where plugs made of small discs of an alloy similar to the body metal (probably from a sprue) were inset into carefully prepared holes left by the core pins and soldered into position.

**Figs. 478, 492**

## Slide 16: Fabrication: Chasing

%%Chasing%% required a variety of tools, including claw chisels, %%punches%%, scrapers, and burnishers to reduce marks from fettling and to close up surface %%porosity%% and small blemishes. Decorative details would be introduced or reinforced with %%engraving%% tools and punches, and a final finish might be achieved with a series of graded polishing agents. Tool marks retained on the surfaces of the aquamanile suggest their transformation closely followed Theophilus’s description that “you first file over all the grounds with various files—square, triangular, and round, then engrave with the engraving tools and scrape with scrapers. Finally, . . . clean . . . it all over with sand and with sticks slightly rushed at the top.”

**Figs. 493, 494, 495, 496, 497**

## Slide 17: Summary of findings

The physical evidence encountered during the technical study of the representative grouping of aquamanilia and a few related objects in this study resonates with Theophilus’s description of the casting of a censer. By adopting as closely as possible the practices and materials described in the treatise, the experimental reproduction of one of the Met’s lion aquamanilia allowed us to better understand the technical parameters of the originals, even the re-creation of an unintended casting flaw. Techniques and materials used in casting aquamanilia remained fairly consistent over the course of their creation, but as their forms became more complex, adaptations were made. And some regional variations in methodology were noted. For instance, in addition to the idiosyncratic core plugs, the aquamanilia cast in Nuremberg sported separately cast spigots, and the %%brass%% alloy used was consistently high in zinc.

**Fig. 498**

## Slide 18: Synopsis of technical study parameters

The research was undertaken in collaboration with the Bard Graduate Center for Studies in the Decorative Arts, Design, and Culture and culminated in a 2006 exhibition in New York at the Bard Graduate Center accompanied by a catalogue: *Lions, Dragons, and Other Beasts: Aquamanilia of the Middle Ages, Vessels for Church and Table*. The various aspects of the technical examination were conducted as part of the day-to-day responsibilities of the Objects Conservation Department at the Metropolitan Museum. While no specific log was kept of time spent, the research, associated teaching, travel, and writing represented the better part of two years’ work. Unless otherwise stated, the examination and analysis was undertaken at the Met:

• endoscopic and microscopic examination of interior and exterior surfaces

• visible-light photography of exterior and interior surfaces

• surface analyses by qualitative X-ray fluorescence (XRF) analysis of disparate elements incorporated either at the time of manufacture or as part of a later restoration

• X-radiography

• scanning electron microscopy (SEM) and polarized light microscopy of core and investment material (Scientific Research Lab, Museum of Fine Arts, Boston)

• X-ray diffraction (XRD) analyses of discrete samples of the polishing compounds and pigments

• inductively coupled plasma mass spectrometry (ICP-MS) analysis of metal samples (Rathgen-Forschungslabor, Berlin)

• replication casting (Ubaldo Vitali)

• video documentation and editing (Bard Graduate Center for Studies in the Decorative Arts, Design, and Culture)

## Slide 19: Further questions

• Many aquamanile and other cast medieval objects examined in European collections retain significantly more core material than the corresponding material in US collections. What might we learn from the analysis of a broader selection of core samples? Might further analysis corroborate some of the groupings made on stylistic grounds? Are there detailed enough geological maps of Germany to allow for the identification of geologic sources for the materials comprising their clays? And what additional information might be gleaned from the shape and size of the component grains?

• What technical relationships might we find between aquamanilia, other small-scale cast objects, and monumental works of art from the same period?

**Fig. 499**

## Slide 20: Further resources

{Bourgarit and Thomas 2015}

{Cellini [1568] 1967}

{Dandridge 2018}

{Barnet and Dandridge 2006} and the DVD insert: Ubaldo Vitali and Pete Dandridge, *Medieval Alchemy and the Making of a Lion Aquamanile*, documenting the replication of a lion aquamanile

{Magnus 1967}

{Mende 2013}

{Theophilus [ca. 1122] 1979}

## Slide 21: Acknowledgments

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