The 5th-century AD riverine boat of Santa Maria in Padovetere: 3D reconstruction of its shape and context

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Abstract
The digital survey of a 5th century AD riverine boat, together with direct measurements and drawings, has led to a complete 3D model of the boat, with deformations corrected, hull lines reconstructed and missing parts recreated. The different construction solutions of this boat (sewing, mortise-and-tenon joints, clinker planks) have been represented in a detailed 1:1 scale for improved study and display. The discovery of this boat in a tributary of the Po River has allowed for some considerations about the environment in which the boat was built, and about riverine navigation in the Po Valley in late antiquity.

Keywords
Digital survey, Late Roman Period, 3D modelling, sewn boat

Résumé
Le relevé numérique, les mesures directes et les dessins d’un chalun fluvial du v° siècle apr. J.-C. ont conduit à la réalisation d’un modèle 3D complet de ce bateau. Ce modèle permet de corriger les déformations, de restituer le plan de forme et les pièces manquantes de la coque. Les différentes techniques de construction de cette embarcation (couture, tenons et mortaises, planches assemblées à clin) ont été représentées de manière très détaillée à l’échelle, afin de permettre une étude et une présentation précises. La découverte de l’épave dans un affluent du Pô a aussi porté à une réflexion sur l’espace nautique spécifique dans lequel le navire a été construit ainsi que sur la navigation fluviale dans la plaine padane à la fin de l’Antiquité.

Mots clés
Relevé numérique, Antiquité tardive, modélisation 3D, bateau cousu

Digital survey techniques are well established in the field of nautical archaeology for the documentation of wooden ship and boat remains. Multi-image photogrammetry, laser scanning, and video and photograph recording contribute to the elaboration of virtual 3D models that facilitate precise studies of ancient ship construction (Jones et al. 2013; Zhukovsky et al. 2013; Pulak et al. 2014, p. 43-45; Dumas et al. 2015; Costa et al. 2016; Yamafune et al. 2016). Three-dimensional surveys of boats are powerful tools for virtually preserving and protecting the archaeological source, but also for obtaining a 3D reconstruction of the original shape of a boat. In this way, we gain a complete visualisation of the hull, which can be employed for better understanding of the construction technique and hull lines, as well as calculations regarding the hydrostatics and stability of the ship (Poveda 2015, 2017; Tanner 2018; Tanner et al. 2020).

The aim of the research was the realisation of a virtual model of the boat of Santa Maria in Padovetere and the environment in which the boat was built and navigated. The remains of the hull were well preserved and included important elements for the identification of the shape: the bottom and the stern to provide the longitudinal shape of the vessel; and the complete starboard side and the frames to provide the shape of the hull in cross section.

1. THE SITE AND THE SHIPWRECK

The boat of Santa Maria in Padovetere was investigated in 2014 and 2015, during two seasons of excavations organised by the Soprintendenza per i Beni Archeologici dell’Emilia Romagna in collaboration with Ca’ Foscari University (Beltrame, Costa 2016, p. 253-255). The site is 4.5 km west of the city of Comacchio, in Ferrara province, on the plain of the Po Delta that was reclaimed in the 1950s (Balista et al. 2007, p. 19).

The boat was located a few metres south of a chapel dated to the 6th century AD, on the northern bank of an ancient river. It was conserved in a thick layer of sand and clay and lays on the starboard side with the flat bottom at roughly 40° to vertical (fig. 1, right). At the end of the excavation, the boat was left in situ and reburied.

The ‘end of life’ of the boat can be dated both by artefacts found within a thick layer of flood sediments covering and in direct contact with the hull, and by the radiocarbon dating of a piece of rope from the hull, providing a terminus ante quem in the second half of the 5th century AD.

We suspect it sank during a heavy flood that may have ripped the barge from its moorings, but since it lays on a riverbank and the majority of the inner planking was not conserved, we cannot exclude the possibility that it was simply abandoned (Beltrame, Costa 2016, p. 265).

The parts at a lower level (starboard side, stern and part of the bottom) were found in a layer of clay in which anoxic conditions guaranteed perfect preservation of the wood. The portion in the upper level was found in a sandy layer that had compromised and damaged the wood. The deterioration of the upper parts suggests a less rapid covering, which left the wood exposed. Probably, the water level reached the height of the port profile of the bottom, causing the total disappearance of the emerged side, even though
the possibility of an impact from agricultural activity in the following centuries must also be taken into consideration.

The hull measures a maximum of $17 \times 2.9$ m and the preserved complete starboard side is 1.45 m in height at midships. It is a typical flat-bottom riverine boat with a box-shaped section. The main assembly system used by the shipwright is the sewn technique on a bottom-based construction system. In this technique, the planks are sewn together by running stitches (while the frames are joined to the planking by wooden pegs) and the sewing holds vegetal wadding placed over the seams prior to sewing. This technique was widespread in the area delimited by the coasts and the inland waters of the northern Adriatic where it was the most commonly used technique for the construction of inland boats in the Roman and probably Late Roman Periods (Beltrame 2002; Beltrame, Gaddi 2013; Pomey, Boetto 2019, p. 12-16).

A very original aspect of this boat is the use not only of the sewing technique but also of two other techniques for joining the planking to the sides: mortise-and-tenon joints and a sort of very unusual, at least for the Mediterranean, overlapping of planks (clinker) with iron nails every 1 metre.

2. DIGITAL TECHNIQUES

2.1. THE SURVEY AND THE 3D MODEL OF THE HULL IN SITU

After the production of a digital model of the hull using automatic photogrammetry, integrated with total station surveying and laser scanning, the first phase of the data elaboration of the virtual model was the realisation of orthophotos in order to develop plans and sections, necessary resources in archaeological interpretation (Costa et al. 2016). We then pursued the research with 3D reconstructions of every single wooden element, and we have reconstructed a virtual textured model perfectly matching the real object.

The polygonal modelling of the boat does not replace the virtual model obtained through the photogrammetry survey, since the two models represent two different types of visualisation: the photogrammetry model is a realistic copy of the subject, with millimetric accuracy and the exact chromaticity of the subject, while the reconstructed model is intentionally schematic to facilitate the operations of reconstruction and the interpretation of the hull shape and structure. In Figure 1, the development from photogrammetry to polygonal model is shown.

The photogrammetry model represents the boat in situ with the sediments preventing the collapse of the frames, whereas modelling and reconstruction can highlight hidden elements, make the non-visible parts of the boat accessible, and eliminate details such as cracks in or degradation of the wood. For complete documentation, the boat should be dismantled, but this was not possible without a programme of recovery and restoration (fig. 1).

2.2. THE MODELLING AND THE RECONSTRUCTION OF THE HULL

The realisation of the virtual model of a complete side (starboard) and a complete end (stern) led to the reconstruction of
the original shape of the boat and the hull lines through the correction of the distortions of the shape (Jones et al. 2013, p. 124-125; Poveda 2017, p. 30-31; Tanner 2018, p. 143-144).

The first operation to reconstruct the original hull shapes was the rotation of the hull to the navigation position. Once this operation was completed, the deformation of the bottom planks, longitudinally and transversally, was evident, showing how these were eased down on the bank, losing their original structure. It was necessary to develop and extend the planks to reconstruct the correct shape of the bottom along the horizontal axis without dimensional variations (Ravn 2012, p. 316). The distorted planks of the right side had to be bent, rotated and twisted without modifying the real measurements of the plank. At the stern and the stem, it was not possible to join the first plank of the side with the bottom without bending the bottom itself to connect to the side in a raised position, with a lift of 22 cm at the stem and 12 cm at the stern, acquiring a plausible curvature for correct hydrodynamic functioning. The existing frames were used to evaluate the degree of deformation of the planks due to post-depositional factors, and they were reconstructed, eliminating the deformations, modelling where necessary, and integrating the terminal part of the bottom portion based on the symmetrical twin frame.

An important modelling phase concerned those elements whose shapes and dimensions could be reconstructed on the basis of clear signs of their existence in the hull, such as the stem, the beams and the deck planks. In contrast, other elements, such as the rudder or the bow mast, are hypotheses based on archaeological and ethnographical comparisons (fig. 2) (Casson 1995, p. 329, 336-337; Boetto 2008, p. 46-47; Marlier, Poveda 2014, p. 209, 214-215).

The side planks near the stem were deteriorated and did not run the total length. In order to determine the shape of the stem, the lines of the side were automatically extended following the curvature until reaching a vertical plane passing through the central axis of the hull. The lines thus generated were the most probable because they were created along a very small missing portion (1-2 m) in respect to the length of the entire plank (18-20 m), for which we know the correct curvature.

A series of transversal beams were reconstructed on rectangular notches cut at regular distances on the shelf clamp; they were slightly inclined, following the line of the rectangular cuts and the curvature as confirmed by ethnographical comparison. The beams were used as support for the deck planks and the presence of a separated deck in three parts was hypothesised, corresponding to transversal elements positioned at a distance that would permit walking on the deck planks without breaking them.

2.3. CONSIDERATION OF THE SHAPE AND THE PROPULSION OF THE BOAT

By redressing the deformation of the wooden structure, the reconstruction of the boat has allowed improved observations of construction aspects, and a hypothesis as to its length being around 23 m, maximum width of 5 m, and height of 1 m in the middle section and 2.20 m at the stern (fig. 3).

This is one of the few boats used only for inland navigation during the Late Roman Period in southern Europe for which the almost complete shape is known (Rieth, Guyon 2010; Marlier 2014).

Its use as a river transport boat is indicated by the flat bottom and by the absence of evidence both of a closed deck and a sail mast. We do not have any archaeological information regarding the propulsion of the boat, but we can consider the words of Latin authors who mention towing (Gaius Valgius Rufus, fr. 4) and oars (Martial, Epigrammatica libri, III, 67, 1–4) when describing
navigation along the waterways of this area. The width of the last beam toward the stem, that measures 40 cm instead 10 cm as the others beams, and some comparisons (Boetto 2008, p. 46-47; Marlier, Poveda 2014, p. 209), let us suppose the presence of a small mast to tow the boat from the riverbank.

The high sternpost invites comparisons with iconographic images from Central Europe, dated to the Roman Period (Beltrame, Costa 2016, p. 12). This end and the rise of the sides at this part, which could be suited to providing a clear view and good control of a long central steering oar, might suggest the...
presence of a helmsman in this area. The shape of the steering oar has been reconstructed from detail on a relief on the base of the statue of Tiber held in the Louvre and through comparisons with the steering oar of Arles-Rhône 3 (Casson 1995, p. 329, 336-337; Marlier, Poveda 2014, p. 214-215).

Long central single rudders were employed on different types of flat-bottomed boats along the rivers of Central Europe in the 18th century and until the beginning of the 20th century (Beaudouin, 1985, p. 73; Ossowski 2010, p. 138). Such comparisons suggest that the long pin passing through the stern and the L-shaped element on the deck might be connected to the helmsman’s post, although the question of the use of the central pin is still open.

3. THE RECONSTRUCTION OF THE ENVIRONMENT AND THE TRANSPORTED CARGO

Matter collected in the bilge of the wreck and deposited during the use of the barge, such as pollen, plant remains and some remains of the transported cargoes, can assist in the reconstruction of the environment where the boat navigated. The landscape of the plain has been identified as a patchwork of open areas, deciduous mesophilic mixed woods (Quercus, Ulmus, Carpinus, Corylus, Fraxinus and Acer) and some stands of Mediterranean evergreen oak (Quercus ilex). The rare presence of pollen from Pinus pinea could be the first direct evidence of Roman cultivation of this species on the Adriatic coast of Emilia Romagna. The predominance of wild riparian wood pollen taxa (Alnus, Populus, Salix and Sambucus nigra type) and pollen grains of hygrophytes suggests a freshwater environment. The relatively high and unusual pollen percentage of the dry meadow plant Sanguisorba minor and the co-occurrence of some other meadow species could be related to the use of the barge for the transportation of animals and their forage. The presence of spores produced by fungi that grow in dung supports the same hypothesis (Marlier 2014, p. 277; Beltrame et al. 2019, p. 3, 14-15) (fig. 4).

4. CONCLUSIONS

The anoxic conditions of the archaeological deposit have provided rare evidence of a flat-bottomed barge of the mid-5th century AD that can tell us much about ship construction and navigation along the rivers and canals of the Po Delta.

The digital survey of the hull documented in situ and the possibility of employing digital modelling techniques allowed us to study and analyse a particular type of boat and to reconstruct the complete shape of the hull with a high percentage of reliability, due to the fortunate conservation conditions of the shipwreck. The important contribution of geomatic techniques was crucial for the virtual modelling of the existing parts, since the excavation data was difficult to exploit due to the deformation of wooden elements, and for the reconstruction of the hypothesised elements.

Our experience serves to emphasise that the correct approach to 3D documentation of cultural heritage is to employ and integrate multiple sensors and technologies (photogrammetry, laser scanning, modelling, computer graphics, etc.), taking advantage of the intrinsic potentials of each technique. The effectiveness of these new procedures confirms digital technologies as an important and essential tool for the documentation, study and visualisation of nautical cultural heritage: this is a tool that seems to improve as research advances.

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