# Digital reconstruction hypothesis of the Roman-era fluvial barge from Kamensko, Croatia

Anton Divić – Giulia Boetto – Krunoslav Zubčić – Pierre Poveda

**Abstract:** The Kamensko barge sank to the bottom of the Kupa River sometime between the 1st and 3rd centuries AD. Its well-preserved remains, discovered in 2009 on the riverbed in the vicinity of Karlovac in Croatia, were excavated between 2015 and 2018. The quantity and quality of the obtained documentation allowed the reconstruction hypotheses of its hull shape, structure and technical system to be proposed and modelled through an exclusively digital approach, whose outlines will be presented in the text below.

**Keywords:** 3D reconstruction, flat-bottomed barge, Kupa River, nautical archaeology, fluvial navigation

## 1. The wreck

The Kamensko wreck is that of a flat-bottomed river barge from the Roman period, dated to between the 1st and 3rd centuries AD.[1] On its last journey it was transporting a cargo of several hundred construction bricks. Its remains, 2.1 m wide and 12 m long, are located on the riverbed of the Kupa River downstream of Karlovac in Croatia (Fig. 1). The remains consist of two massive bilge strakes, obtained by hollowing out two oak trunks, that form the sides and part of the bottom of the barge. Between them, two bottom strakes made from four planks are inserted.


**Fig. 1** Position of the Kamensko site (map: V. Dumas, A. Divić)

A forward-placed rectangular longitudinal mast step has been preserved *in situ,* allowing for the identification of the surviving extremity as the bow of the barge. The barge is transversally reinforced by five pairs of frames attached to the

[1] According to AMS radiocarbon dating of two samples, one effectuated in Vienna Environmental Research Accelerator (40 BC–230 AD, 95.4% probability) and the other in Centre de Datation par le Radiocarbone in Lyon (82–234 AD, probability of 95.4%). The BC dates were not taken into account as brick production along the Kupa seems to have developed from 1st century onwards (for more details see Divić 2022a: 249–250).

hull by treenails. The strakes are assembled by numerous closely spaced iron clamps, driven both from the outside and inside of the hull. The barge presents interesting structural features that place it in close relation with several other Roman-era shipwrecks from the Danube hydrographical basin (Pomey, Boetto 2019; Boetto, Divić, Zubčić 2021; Divić 2022a; Divić 2022b).

The Kamensko wreck was excavated between 2015 and 2018 by a team from the Croatian Conservation Institute and the Centre Camille Jullian, making it the first fluvial wreck to be systematically researched in Croatia. Each stage of the excavation was accompanied by meticulous documentation in the form of measurements, drawings, general and detailed photographs, and 3D photogrammetric models used to generate orthographic images, plans and cross-sections.

## 2. The methodology

As well-stated by one of the forefathers of nautical archaeology, research and reconstruction are practically synonyms in the interpretation of shipwrecks (Steffy 1994: 214). This is also true for the Kamensko wreck, as the idea of the barge's original shape, structure, and technical system evolved constantly during the four campaigns of extensive fieldwork and many hours of post-excavation documentation and analysis. In addition to the study of the meticulously documented remains of the wreck, the original form of the barge was reconstructed through comparison with archaeological, iconographic, and ethnological parallels.

The reconstruction hypothesis of the Kamensko barge shape, structure, and technical system was, however, achieved through the application of an exclusively digital process following the latest approaches that are becoming standardised within the framework of nautical archaeology (Poveda 2012; 2015), in accordance with the established experimental boat and ship archaeology principles (Coates *et al.* 1995). The barge's architecture and technical system were three-dimensionally modelled in Rhinoceros 3D, a commercial 3D computer graphics and computer-aided design (CAD) software.

The first step in this process was the creation of a 3D CAD model of the preserved remains that would serve as the basis for the subsequent reconstruction (Fig. 2). This was achieved mainly through the use of georeferenced three-dimensional photogrammetric models, generated for every stage of the excavation, which served as a base layer for the CAD 3D modelling of the remains in the Rhinoceros software.

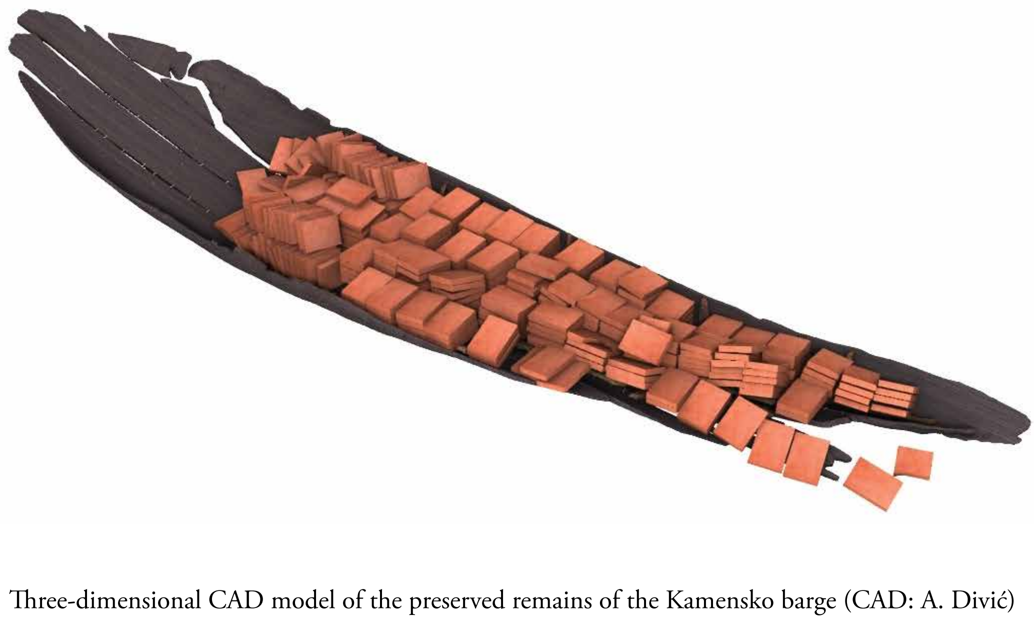

**Fig. 2** Three-dimensional CAD model of the preserved remains of the Kamensko barge (CAD: A. Divić)

The information that could not be extracted directly from the photogrammetric models was supplemented by the fieldwork documentation: numerous measurements, sketches, plans, observations, and detailed photographs. This direct documentation proved to be an invaluable asset to the creation of the three-dimensional model of the remains and the subsequent reconstruction, which could not have been rendered solely on the basis of photogrammetric documentation. It is the abundance of high-quality documentation, combined with the high level of preservation of the barge, that has enabled the reconstruction of the hull shape, structure, and technical system with a good level of certainty.

## 3. Hull size and shape

As the remains of the Kamensko barge are preserved to a length of 12 m and the stern part of the vessel is missing, one of the greatest challenges in formulating the reconstruction hypothesis was determining the original length of the barge as well as its stern shape. In the absence of material remains that would allow for these elements to be reconstructed, parallels with similar vessels with a high level of preservation that operated in similar nautical spaces and in chronological relationship with the Kamensko barge were invoked.

For the reconstruction of the original length of the barge, two factors were taken into account. First is the ratio between the total length of the barge (L) and the distance measured between the recess for the mast and the bow (MR-BD). This approach was made possible due to the fact that both the mast step and the forward end of the Kamensko barge have survived *in situ* relatively intact, while the well-conserved and documented wrecks of other inland vessels from the Roman period have allowed parallels to be drawn between them.[2]

The barges taken into consideration are Arles-Rhône 3 (Marlier 2014), Bevaix (Arnold 1992a), and Zwammerdam 6 (de Weerd 1988), all documented and preserved almost in their original length with their mast steps preserved *in situ*. The dimensions of the three aforementioned Roman barges, as well as the L/MR-BD ratio, are presented in Table 1.

| Barge | Length (m) | Beam (m) | Mast recess – bow distance (m) | L/MR-BD ratio |
|---|---|---|---|---|
| **Arles-Rhône 3** | 31 | 3.07 | 9.16 | 1: 3.38 |
| **Bevaix** | 19.35 | 2.8 | 5.65 | 1: 3.42 |
| **Zwammerdam 6** | 20.4 | 3.4 | 6.05 | 1: 3.37 |
| **Average** | | | | **1: 3.39** |

**Table 1** Sample of three Romano-Celtic inland barges used to calculate an average ratio between the total length of the barges (L) and the distance measured between the recess for the mast and the bow (MR-BD).

As can be seen from the above-presented sample, the position of the towing mast does not seem to have differed greatly between these three Roman-era inland vessels belonging to different regional sub-groups that operated in different nautical transport zones across the Roman Empire. All three barges had their mast mortises positioned almost identically in relation to their extremities, approximately one-third of the total length from the bow and two-thirds from the stern.

Due to the good level of preservation of the Kamensko's bow and mast step, the same calculation can be applied to obtain a first hypothesis of the original length of the barge. The distance between the mast step mortise and the bow amounts to 4.86 m. When multiplied by the average mast L/MR-BD ratio of 3.4, this method allows us to propose 16.52 m as the first hypothesis of Kamensko barge original length.

This first length hypothesis can be evaluated by comparing the length/beam (L/B) ratio of some well-preserved inland barges from Roman period (Tab. 2) to the one obtained with the L/MR-BD ratio. Presenting a particular elongated shape suited to their navigation areas, with a L/B ratio much greater than their maritime counterparts, these slender, box-shaped vessels were built to facilitate their movement through often narrow canals and to reduce water resistance when hauled upstream. The preserved beam of the Kamensko barge (2.1 m), multiplied by the average L/B ratio calculated from a significant sample of Roman-Celtic inland vessels whose state of conservation and availability of publications allowed for a viable reconstruction of their original size, should allow for a validation or a mitigation of its above-reconstructed length.

[2] Masts of Roman inland vessels were rarely part of a sailing rig, but rather served as supports for cables used for towing, a particular method of upstream river navigation well documented in Roman archaeological and iconographic sources (Arnold 1992b: 84–85; Beaudoin 1994; Rieth 1998: 106–107; Boetto 2008; Marlier, Poveda 2014: 209–211). In contrast to the masts of the maritime sailing ships, which are rather placed slightly forward of amidships, the position of towing mast is dictated by this applied mode of propulsion, which requires a forward-placed mast, between the barge's centre of gravity and its bow, approximately at 2/3 of the hull length (Beaudouin 1994: 3; Rieth 1998: 106).

| Vessel | Length (m) | Beam (m) | L/B ratio | Reference |
|---|---|---|---|---|
| **Zwammerdam 2** | 23 | 2.8 | 1:8.21 | de Weerd 1988 |
| **Zwammerdam 4** | 34 | 4.4 | 1:7.72 | de Weerd 1988 |
| **Zwammerdam 6** | 20.4 | 3.4 | 1:6 | de Weerd 1988 |
| **De Meern 1** | 24.6 | 2.6 | 1:9.4 | van Holk 2011 |
| **De Meern 4** | 27 | 3.7 | 1:7.29 | van Holk 2011 |
| **De Meern 6** | 10 | 1.6 | 1:6.25 | van Holk 2011 |
| **Woerden 7** | 29.6 | 4.7 | 1:6.29 | van Holk 2011 |
| **Lyon PSG 4** | 28 | 4.85 | 1:5.77 | Guyon, Rieth 2011 |
| **Lyon PSG 7** | 40 | 5 | 1:8 | Guyon 2010 |
| **Arles-Rhône 3** | 31 | 3.07 | 1:10 | Poveda 2014 |
| **Bevaix** | 19.35 | 2.8 | 1:6.9 | Arnold 1992a |
| **Average** | | | **1:7.44** | |

**Table 2** Sample of 11 Romano-Celtic barges used to calculate their average length/beam (L/B) ratio.

As seen on the sample of 11 Romano-Celtic barges, their length-beam ratio varies between 1:5.7 and 1:10, with the average ratio calculated at 1:7.4. In practical terms, this would mean that a 1-meter-wide vessel with 1:7.4 beam-length ratio would have the length of 7.4 m. When applied in the case of Kamensko, with its beam conserved in its entirety and measuring 2.10 m, this second hypothesis reconstructs the barge's original length to 15.62 m. Considering the median value of the two length reconstruction hypotheses, the original length of the Kamensko barge is therefore reconstructed to approximately 16 m (Fig. 3).

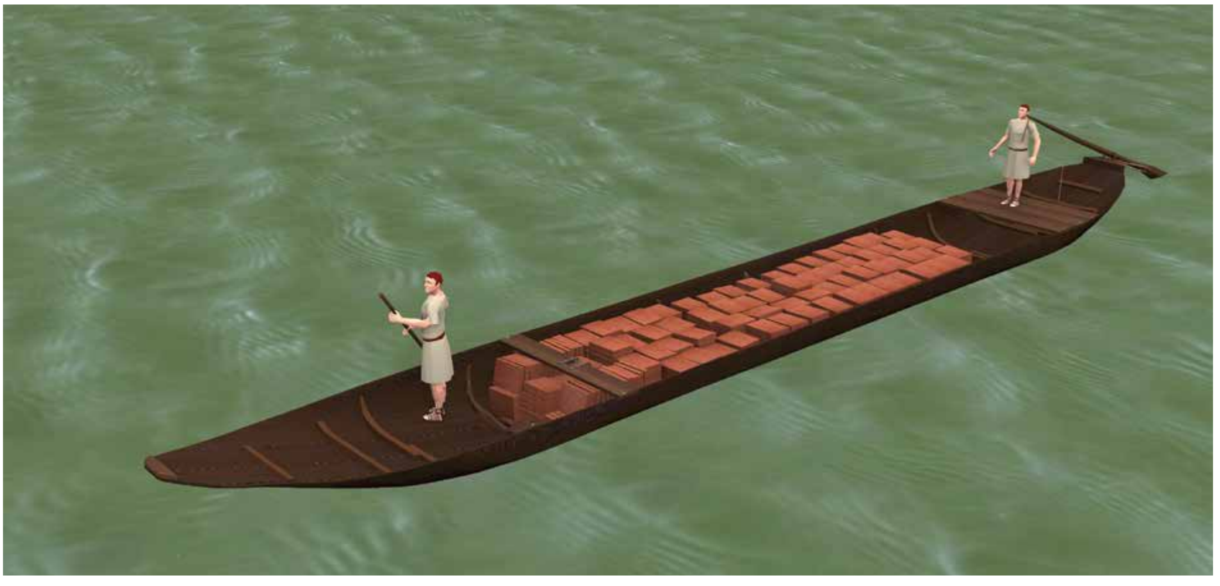

**Fig. 3** Hypothetical reconstruction of the Kamensko barge navigating downstream during its last voyage (CAD: A. Divić, P. Poveda)

Parallels with the afore-mentioned barges (Tab. 1 and 2) were once again invoked for the reconstruction of the missing stern of the Kamensko barge. Although different in shape and size, and belonging to different shipbuilding traditions, most of these barges present a symmetrical shape, as do the majority of modern traditional fluvial vessels. In light of these considerations, and in particular due to the lack of the possibility to introduce any kind of evidence that indicate otherwise, the shape of the stern of the Kamensko barge has been reconstructed as a mirrored version of its bow.

## 4. The propulsion system

As is very often the case with ancient wrecks, the propulsion and steering systems of the Kamensko barge did not survive the wrecking and site formation processes and need to be reconstructed by deduction as well as through comparison and analogies with their counterparts documented in archaeological, iconographical and ethnographical sources.

The only surviving element of the Kamensko barge related to its propulsion is the mast step. However, what type of mast did it house? Was it a towing mast, a mast for hoisting a sail rig, or could both have been used? The idea of the use of sail on the Kupa was dismissed due to several reasons: the relatively narrow width of the river, which would hinder any manoeuvres; the morphology of the Kupa, presenting numerous meanders; the absence of prevailing winds; and no documented use of sail in the ethnological record.

The use of towing as an upstream propulsion method during the Roman period, on the other hand, has been well documented in contemporary sources. In addition to the well-preserved towing mast of the 1st century AD Arles-Rhône 3 barge (Marlier, Poveda 2014: 209), towing scenes are depicted on several low-reliefs such as those from Cabrières-d'Aigues (Cavalier 2008) and Igel (Béal 1999: 95–103), as well as immortalised by the writings of the 4th century poet Ausonius (Idyllia X, Mosella).

Some of the above-presented archaeological, iconographic, and written sources, reinforced by historical and ethnographical studies of 18th and 19th century navigation on the Kupa (Divić 2022a: 81–109), allow for the conclusion that the mast recess of the Kamensko barge housed a towing mast. With one or more towing cables attached to its masthead, the barge was propelled on its journey upstream by being pulled by a group of several men, or less likely pack animals, from the riverbank.

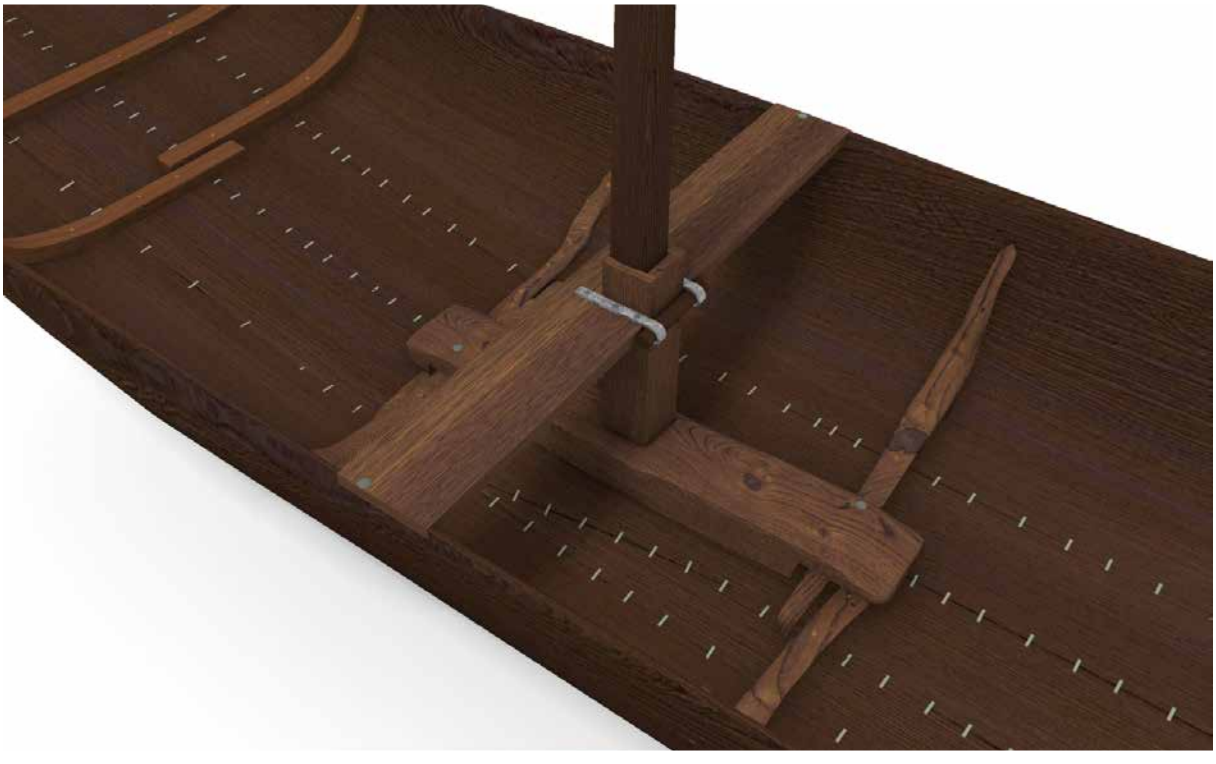

**Fig. 4** Reconstruction hypothesis of the locking mechanism of the Kamensko mast ensemble (CAD: A. Divić)

The evidence that allowed us to reconstruct this propulsion system in more detail came in form of three rectangular notches imprinted into the upper face of the mast step. With a width of 3-4 cm and a length up to 15 cm, these notches are interpreted as traces of three planks that formed the structure to support the mast in place. Those would require a transverse support in the form of a beam, perhaps similar to the one recoded on the contemporary Zwammerdam 4 shipwreck (de Weerd 1988: 149, 152), whose secondary function would be to provide the barge with additional transverse support. This combination of direct evidence and archaeological analogies allowed the reconstruction of the Kamensko mast ensemble (Fig. 4) as a probable hypothesis.

## 5. The steering system

As no elements of Kamensko's steering system were preserved in the riverbed, a *possible* reconstruction (Pomey, Rieth 2005: 148; Poveda 2014: 40–41), based not on direct archaeological evidence but on parallels and analogies with other archaeological, iconographic and ethnographic sources, was effectuated.

In addition to the steering oars from Bevaix (Arnold 1992a: 95) and Arles-Rhône 3 (Marlier, Poveda 2014: 213–214), iconographic representations from the Roman period proved to be a trove of detail regarding the attachment and handling of these devices, in particular the detailed depiction from the 1st century Cologne stele (Arnold 1992b: 85). Reinforced by a number of ethnographic contributions that testify to the use an axially positioned steering oar within the Kupa basin (Divić 2022a: 101–109), the Kamensko steering oar has been reconstructed as such (Fig. 5).

**Fig. 5** Reconstruction of the Kamensko steering oar and its attachment system to the stern (CAD: A. Divić, P. Poveda)

Such an axially positioned steering oar would have been attached with ropes to the stern of the barge and fixed in place in a way that would prevent any lateral movement, allowing for an axial rotation of its shaft. With its blade immerged, the steering oar would have been manipulated by the steersman through lateral movements of a tiller driven vertically through the shaft, thus ensuring the desired direction of the barge.

An axially positioned, stern-mounted steering oar would need to be supplemented with a stern platform which would facilitate its handling and provide the steersman with a better line of sight. The existence of such platforms is depicted on a majority of the above-mentioned low reliefs and has been deduced from the archaeological remains of Bevaix (Arnold 1999) and Arles-Rhône 3 (Poveda 2014: 226–228) barges. During downstream navigation, the stern steering oar could have been supplemented by an oar placed at the bow of the barge, as depicted on the Blussus stela and attested in the ethnological record (Divić 2022a: 108–109; Hefele 1896: 73).

## 6. Hydrostatic analyses

This digital reconstruction method allowed for the development of a complete reconstruction hypothesis which, in addition to its educational and presentational purposes, can primarily be used for scientific analyses: to simulate the cargo capacity, displacements, and evaluate the navigational capabilities of the ship within its area of navigation. Every architectural element has been modelled and had its respective material and characteristics assigned to it (type of wood and the corresponding specific weight), which allowed us a straightforward calculation of their volume and weight. This, in turn, led to a relatively simple calculation of the barge's displacements and tonnage, while the combination of the obtained data and the reconstructed hull lines allowed the generation of accurate hydrostatic analyses.

The hydrostatic analyses were calculated in Orca 3D, a naval architecture and marine design plug-in for Rhinoceros 3D software. These simulations were used to calculate the barge's light displacement, deadweight tonnage, and loaded displacement[3] (Fig. 6).

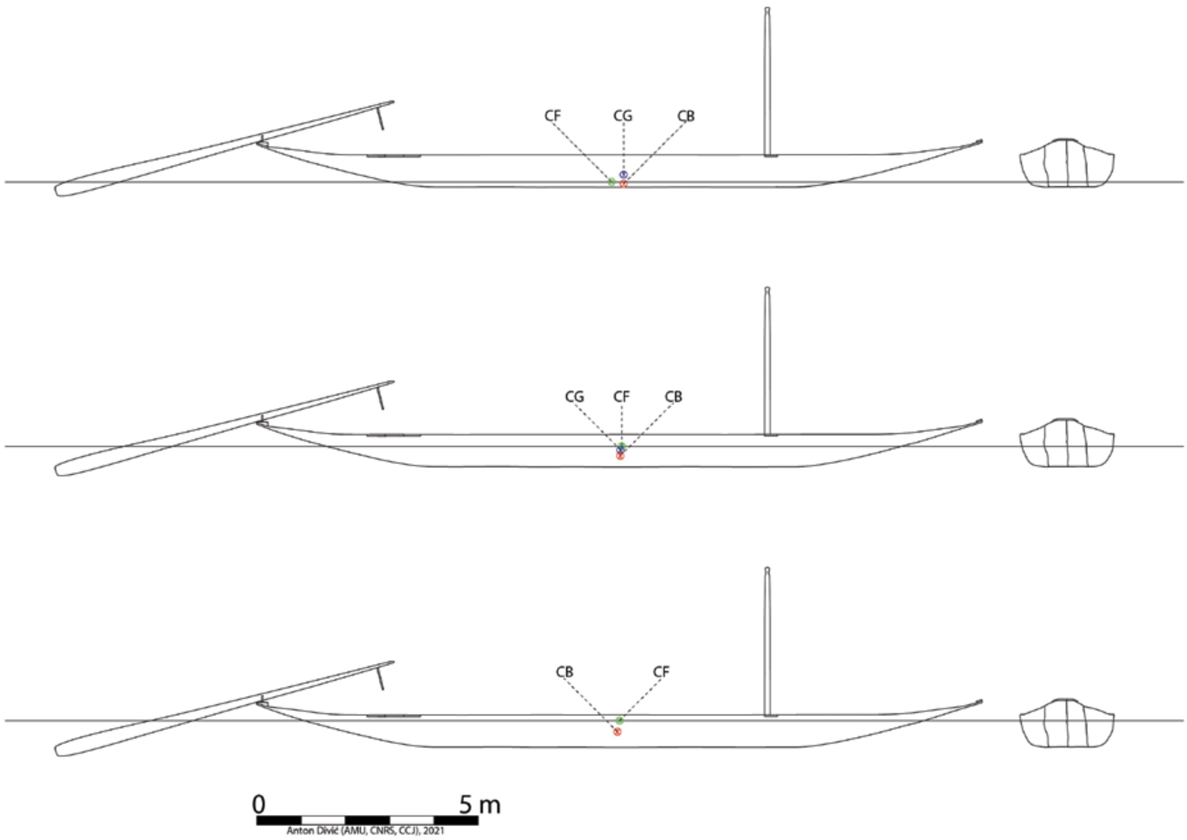


**Fig. 6** Three levels of displacement of the Kamensko barge in accordance to the water level: light displacement (up); loaded displacement (middle); maximal displacement (down) (CAD: A. Divić, P. Poveda)

[3] The 'Weight and Cost Reports' generated in Orca 3D for both light and loaded displacement of the Kamensko barge's hull reconstruction (including the hull's LCG's, TCG's, and VCG's) have been omitted from this publication due to spatial constraints, but have been included in the co-author's PhD thesis (A. Divić 2022b: 161).

With its reconstructed dimensions of 16 m in length, 2.1 m in width, and 0.70 m in depth, the 3D reconstruction allowed the volume of the barge's structural and assembly elements to be calculated at 2.45 $m^3$. The combination of the volume of each of the barge's elements with the density of the woods used in the construction permitted us to evaluate the barge's light displacement to be 2.1 metric tons, with a draught of 0.10 m when sailing empty.

Although the majority of the barge's brick cargo remained preserved *in situ*, the aft cargo disposition was unknown due to the lack of archaeological remains; however, the reconstructed shape and volume of the hull allowed the complete cargo disposition to be reconstructed as well. As correctly assumed at the early stages of excavation, the barge transported approximately 600 bricks occupying a volume of 4.6 $m^3$. With each brick weighing 11 kg on average, together with the 140 kg of dunnage in form of tree trunks and branches, the barge's deadweight tonnage at the moment of the wrecking was calculated to be 6.7 t.

The combination of barge's deadweight tonnage and its light displacement allowed for its loaded displacement to be calculated using the 'Hydrostatics & Stability Analysis' of the Orca 3D software. On its last voyage, the Kamensko barge is presumed to have had a displacement of 8.8 t, which would have resulted in a draught of 0.47 m, exactly 2/3 of the hull's total depth. The freeboard of 0.23 m would have allowed the barge to navigate without fear of flooding, thus eliminating overload as a possible cause of sinking as was envisaged in the initial stages of excavation.

## Acknowledgments

We would like to thank all the participants of the excavation campaigns and, in particular, Loïc Damelet and Vincent Dumas (CNRS, Centre Camille Jullian). The first performed the photo coverage of the remains and the second developed the georeferenced three-dimensional photogrammetric models.

## References


Arnold, B. 1992a. *Batellerie gallo-romaine sur le lac de Neuchâtel, tome 1*, [Archéologie neuchâteloise 12]. Neuchâtel, Musée cantonal d'archéologie.

Arnold, B. 1992b. *Batellerie gallo-romaine sur le lac de Neuchâtel, tome 2*, [Archéologie neuchâteloise 13]. Neuchâtel, Musée cantonal d'archéologie.

Arnold, B. 1999. *Altaripa, archéologie expérimentale et architecture navale gallo-romaine*, [Archéologie neuchâteloise 25]. Neuchâtel, Musée cantonal d'archéologie.

Béal, J. C. 1999. Remarques sur l'imagerie du pilier funéraire d'Igel. In N. Blanc, A. Buisson (eds), *Imago Antiqvitatis, Religions et iconographie du monde Romain*. Paris, De Baccard: 95–104.

Beaudouin, F. 1994. *Les chemins qui marchent…*, [Bulletin de l'Association des Amis du Musee de la Batellerie 32]. Conflans-Ste-Honorine, Association des Amis du Musée de la Batellerie.

Boetto, G. 2008. L'épave de l'Antiquité tardive Fiumicino 1: analyse de la structure et étude fonctionnelle. *Archaeonautica 15*: 29–62.

Boetto, G., Divić, A., Zubčić, K. 2021. A Roman Barge from the River Kupa at Kamensko, Croatia: Evidence of a Regional Shipbuilding Tradition of the Danube River Basin in Southeastern Europe. In G. Boetto, P. Pomey, P. Poveda (eds), *Open Sea, Closed, Sea, Proceedings of the Fifteenth International Symposium on Boat and Ship Archaeology, Marseilles 2018, ISBSA XV*, [Archaeonautica 21]. Paris, CNRS Editions: 115–122.

Cavalier, O. 2008. *La scène de halage de Cabrières-d'Aigues*. Laffont, Presses de l'Impr.

Coates, J., Mcgrail, S., Brown, D., Gifford, E., Grainge, G., Greenhill, B., Marsden, P., Rankov, B., Tipping, C., Wright, E. 1995. Experimental Boat and Ship Archaeology: Principles and Methods. *The International Journal of Nautical Archaeology* 24.4: 293–301.

Divić, A. 2022a. *La rivière Kupa (Croatie): essai de restitution d'un espace nautique et d'un paysage fluvial à l'époque romaine (Volume I)*, PhD Dissertation. Aix-en-Provence, Université Aix-Marseille.

Divić, A. 2022b. *La rivière Kupa (Croatie): essai de restitution d'un espace nautique et d'un paysage fluvial à l'époque romaine (Volume II)*, PhD Dissertation. Aix-en-Provence, Université Aix-Marseille.

Hefele, F. 2002 (1896). *Naši domaći obrti* (Sisak, Tiskara Čupak i Dujak). Zagreb, Dom i svijet.

Marlier, S. 2014. Arles-Rhône 3. *Un chaland gallo-romain du Ier siècle après Jésus-Christ*. [Archaeonautica 18]. Paris, CNRS Éditions.

Marlier, S., Poveda, P. 2014. Présentation et analyse du système mécanique. In S. Marlier (ed.) *Arles-Rhône 3. Un chaland gallo-romain du Ier siècle après Jésus-Christ. Archaeonautica* 18: 209–216.

Pomey, P., Boetto, G. 2019. Ancient Mediterranean Sewn-Boat Traditions. *The International Journal of Nautical Archaeology* 48.*1*: 5–517.

Pomey, P., Rieth, E. 2005. *L'archéologie navale*. Paris,Editions Errance.

Poveda P. 2012. *Le navire antique comme instrument du commerce maritime: restitutions 3D, tonnage, qualités nautiques et calculs hydrostatiques des* épaves : *Napoli A, Napoli C, Dramont E et Jules-Verne 7*, PhD Dissertation. Aix-en-Provence, Université Aix-Marseille.

Poveda, P. 2014. Restitution des formes et études hydrostatiques. In Marlier 2014: 222–231.

Poveda, P. 2015. Méthode de restitution des navires antiques: nouveaux outils et nouvelles analyses des restitutions en archéologie navale. *Revue d'histoire maritime* 21: 157–179.

Rieth, E. 1998. *Des bateaux et des fleuves: Archéologie de la batellerie du néolithique aux temps modernes en France*. Paris, Éditions Errance.

Steffy R. 1994. *Wooden Ship Building and the Interpretation of Shipwrecks*. College Station, Texas A&M University Press.

Weerd, M. de 1988. *Schepen voor Zwammerdam. Bouwwijze en herkomst van enkele vaartuigtypen in West- en Middeneuropa uit de Romeinse Tijd en de Middeleeuwen in archeologisch perspectief*, PhD Dissertation. Amsterdam, Universiteit van Amsterdam.