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Text of the communication “**Digital reconstruction hypothesis of the Roman-era fluvial barge from Kamensko, Croatia**”

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by

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This presentation is focused on the reconstruction process of the Roman flat-bottomed ship found in the Kupa River in Kamensko. After a synthetic overview of the main architectural characteristics of the barge as already presented in the fifteenth edition of the ISBSA held in Marseille in 2018, we will address the theoretical principles behind the hypothesis of reconstruction of the shape and structure, explaining why and how some choices were made. Following will be the presentation of the digital techniques and methods used and, finally, an overview of the hydrostatic data extracted from the 3D model.

Kamensko shipwreck is that of a flat-bottomed Roman-era fluvial barge dated between the 1st century BC and 3rd century AD. Its remains, 2 m wide and preserved in the length of 12 m, are lying on the riverbed of the Kupa in Croatia, together with its relatively intact cargo of several hundred bricks of the type “Lydion”. The shipwreck presents interesting structural features that place it in close relation with several other Roman-era shipwrecks from the Danube hydrographical basin.

The preserved remains of the barge consist of two massive hewn bilge strakes, between which 2 bottom strakes made of 4 planks have been inserted. A forwards-placed rectangular longitudinal mast step has been preserved in situ, as well as 5 pairs of frames attached to the strakes by treenails. Additional joining was achieved with tightly-spaced metal clamps, driven both from the outside and the inside of the hull.

The shipwreck was discovered in 2009 and was systematically excavated between 2015 and 2018 by a team from the Croatian Conservation Institute and the Centre Camille Jullian. Each step of the excavation was followed by meticulous documentation in the form of numerous measurements, drawings, detailed photographs, generation of photo-mosaics and three-dimensional photogrammetric models, continued during the post-excavation phase through the creation of both two-dimensional and three-dimensional site plans.

It was this abundance of high-quality documentation, in combination with the high level of preservation of the barge’s structure, with approximately 54% of the original structure preserved, that allowed its hull to be reconstructed with a fair level of certainty.

The first phase in the reconstruction process was the formation of a theoretical reconstruction hypothesis. This theory of what the barge must have looked like during its last voyage and how it was navigated was not conjured in one instance, but was being developed constantly throughout the four excavation campaigns and numerous hours of post-excavation documentation and analyses, even if remaining only in a theoretical form. Besides through the study of the documented remains of the shipwreck, the original form of the barge was being reconstructed through comparison with archaeological, iconographic, as well as ethnological parallels.

One of the greatest challenges was the attempt to reconstruct the original length of the barge. Two methods were applied, both of them resorting to analogies with preserved Gallo-Roman fluvial vessels.

The first method for reconstructing the original length of the barge took into account the beam-to-length ratio of several well preserved Roman-era fluvial barges. This method was made possible due to the fact that the beam of the Kamensko barge that was conserved in its entirety. For purposes of comparison, a total of 11 Gallo-Roman fluvial vessels were taken in consideration, whose state of conservation and availability of publications allowed for a viable reconstruction of their original size. This resulted in an average beam-to-length ratio of 1:7.4. When multiplied with the 2.10 m beam of the Kamensko barge, its original length can be reconstructed to 15.5 m.

Second calculation introduced in order to validate, deny, or modify the obtained length took into account the position of the barge's mast step in relation to its prow, both of which were preserved in good condition on their original positions. The towing mast on fluvial barges is generally placed well forwards, approximately at 1/3 length from the prow, in order to keep the vessel parallel to the riverbanks and facilitate steering while being towed. The distance between the mast step mortise and the prow in relation with the full length of the vessel was calculated on the example of three Gallo-Roman fluvial barges, all resulting in an almost identical ratio. This ratio, applied in the case of the Kamensko barge, allowed us to propose a second hypothesis of its original length of 16.5 m.

If we decide to apply the middle value of the two close calculations, the original length of the Kamensko barge can be reconstructed around 16 meters.

The missing stern of the vessel was reconstructed as a mirrored version of the well-preserved prow. This decision was influenced by the symmetry that is often found in the number of Gallo-Roman vessels, as well as by the lack of possibility to introduce any kind of evidence that would point otherwise.

As it is very often the case with ancient shipwrecks, both the propulsion and direction system of the Kamensko barge did not survive the wrecking and site formation processes and will need to be reconstructed through deduction as well as through comparison and analogies with their counterparts documented in other archaeological, iconographical and ethnographical sources.

The only surviving element of the Kamensko barge connected to its propulsion is the mast step. However, the first question is what kind of mast did it support: a towing mast, a sailing rig, or both? In short, the possibility of the sail on the Kupa was dismissed due the several reasons: the relatively small width of the river, numerous developed meanders; absence of prevailing winds; no use of sail documented in the ethnographic record. On the contrary, this record testifies the large use of hauling.

These constrains, together with some archaeological, iconographic and textual sources that bear witness to the use of towing as a propulsion method employed on European rivers during the Roman period, allowed for a conclusion that the mast housed in this mast step was a towing one.

The evidence that allowed us for a more detailed reconstruction of this propulsion system came in form of three rectangular notches impressed into the upper face of the mast step, interpreted as traces of three planks that constituted the ensemble supporting the mast in place. Those would require a transversal support in form of a beam, possibly similar to the one recoded at the contemporary Zwammerdam 4 shipwreck, whose secondary function would be to provide the barge with additional transversal support.

For the reconstruction of the missing directional system, the archaeological, iconographical, and ethnographical parallels were once again introduced, speaking in favor of an axially positioned steering oar, complemented with a stern platform that would facilitate its handling and provide the steersman with a better line of sight. The eventual use of oars to keep the vessel in the channel when sailing downstream is also possible.

With the theoretical reconstruction hypothesis established, next stage in the Kamensko barge reconstruction process consisted of its materialization. In accordance with the latest approaches that are becoming standardized within the framework of nautical archaeology, an exclusively digital

approach was undertaken, resulting in a digital, although functional and full-size restitution that can be tried and tested in a repeatable fashion. The barge's architectural structure and technical system were therefore three-dimensionally modelled in Rhinoceros 3D software.

First step in this process was the creation of a 3D model of the preserved remains. This is one of important steps of the process as the archaeological remains will constrain all the following steps.. This was achieved mostly with the help of georeferenced three-dimensional photogrammetric models of the shipwreck that served as a base layer for the 3D drawing of the remains in the Rhinoceros 3D software. The photogrammetric models are made out of a dense triangle polygon meshes, with the triangle points serving as attachment points for the three-dimensional drawing. In this way, the linear drawing of the shipwreck was effectuated that was to serve as a starting point for the subsequent modelling of surfaces, that is, for the rendering of the shipwreck's structure.

Information that could not have been extracted directly from the photogrammetric models was supplemented with numerous measurements and sketches hand-taken during the excavations that proved invaluable to the creation of the three-dimensional remains' model and the subsequent reconstruction.

The creation of the three-dimensional remains' model includes also the parts of the cargo and ship structure that were not visible on the 3D model obtained from the photogrammetry, as the outer surface of the barge. The modeling of the hull's outer shell was effectuated according to the direct recording underwater (ex. Thickness) and on the pieces extracted from the riverbed (sampling of the hull). It also allowed us the extraction of preliminary information concerning the barge's tonnage and displacement. But most importantly, it functioned as a base on which the subsequent reconstruction was modelled, serving as a foundation on which the laid-out theoretical ideas were modelled into a physical form.

The starting point for the reconstruction was the amidships cross-section of the shipwreck that was deemed not to present any post-deposition deformities. The upper edge of the side of the barge's caprail of the well-preserved starboard side was raised for several centimeters due to the traces of wear. The flank of the port side, preserved up the turn of the bilge, was therefore modeled on its starboard counterpart in order to obtain the reconstruction of the amidships cross-section. This amidships cross-section, once established and modelled, served as a reference point according to which the abaft starboard flank, presenting significant levels of distortion, was remodeled. In practical terms, this was achieved by establishing multiple cross sections of the modelled elements and straightening them one by one back to their original position in accordance to the established cross-section. This method was applied for the entirety of the deformed starboard flank. With the starboard flank in place, the shape of its port counterpart was modeled according to it, following however the different dispositions of bottom planks.

This exclusively digital reconstruction method, besides being relatively time and cost effective, allowed for the reconstruction of a full-sized vessel that can subsequently be used for simulating its cargo capacity, displacements, and navigational capabilities within its area of navigation. Every architectural element was modelled in real size and had its respective material and characteristics assigned to it, which allows us a straightforward calculation of their volume and weight. This, in turn, leads to the relatively simple calculation of the vessel's displacements and tonnage, while the combination of the obtained data and the reconstructed lines of the hull allowed precise hydrostatic analyses to be generated in naval architecture software, in this particular case Orca 3D. The hydrostatic studies, however simplified in comparison with those of seagoing vessels, allowed some interesting information to be extracted.

With its reconstructed dimensions of 16.3 m in length, 2.1 m in width, and 0.7 m in depth, the 3D reconstruction allowed the calculation of the volume of the barge's structure including the assembly elements to 2.45 m<sup>3</sup>. This, in turn, allowed the barge's light displacement to be calculated to 2 tons, presenting a navigation draft of 17 cm when navigating empty.

Although the majority of the barge's brick cargo remained preserved in situ, the abaft cargo disposition was unknown due to missing stern of the barge, while the reconstructed form and volume of the hull allowed the full cargo disposition to be reconstructed as well. As correctly presumed in the early stages of excavation, the barge was transporting a cargo of 600 bricks occupying a volume of 4.65 m<sup>3</sup>. With each brick weighting 11 kg on average, plus the 140 kilos of dunnage in form of tree trunks and branches, the barge's deadweight tonnage at the moment of the wrecking was calculated at 6.75 tons.

The combination of barge's deadweight tonnage and light displacement allowed for its loaded displacement to be calculated. During its last voyage, the Kamensko barge is presumed to have had a displacement of 8.84 tons, that would result in a navigational draft of 47 cm, exactly 2/3 of the hull's total height.

Calculations aimed at determining the maximal displacement of the vessel were undertaken as well, by simulating conditions that would lead to gradual sinking of the barge of 5 cm in turn, while still maintaining a minimal necessary freeboard for safe navigation. Which, according to a comparison with a modern document showing sand dredgers from the Haute-Garonne, can be kept at a very minimum. However, if we play it safe and allow for 15 cm of freeboard, the maximal displacement of the Kamensko barge amounts to just over 13 tons, allowing it to transport 11 tons of deadweight tonnage.

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