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The IJsselcog project: from excavation to 3D reconstruction

Wouter B. Waldus, Joep F. Verweij and Henk M. van der Velde

ADC Maritiem, w.waldus@archeologie.nl, J.verweij@archeologie.nl, h.vandervelde@archeologie.nl

André F.L. van Holk

University of Groningen and Batavialand, Andre.vanholk@batavialand.nl

Sander E. Vos

Baars-CIPRO and Technical university of Delft, s.e.vos@tudelft.nl

The 15th-century IJsselcog was lifted in 2016 from the river IJssel near Kampen (the Netherlands). From stern to bow and from starboard to portside about 70% of the original wooden hull is preserved. The combined approach of analogue documentation and photogrammetry enabled the research team to reconstruct the original ship in 2D and 3D, followed by a comprehensive study of its nautical characteristics. The hull volume and height were maximized by the shipbuilders using previously unknown construction elements in cogs, such as wales and vertical riders; shipbuilding traits that are generally applied to 16th- and 17th-century carvel-built cargo ships.

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Key words: cog, cargo ships, underwater excavation, 3D recording and reconstruction, medieval Kampen (the Netherlands), shipbuilding innovations.

The name IJsselcog refers to a 15th-century shipwreck excavated in the riverbed of the IJssel and raised on 10 February 2016. In this article the term ‘cog’ or ‘cog-like cargo vessel’ is used as an archaeological term according to Crumlin-Pedersen’s definition (2000: 239–240). The river itself branches off the river Rhine east of Arnhem and subsequently flows northward (Fig. 1). It passes through the former Hanse town of Kampen and discharges its water into the IJsselmeer (former Zuiderzee). The vessel was detected in 2009 during a survey of the river bottom with sidescan sonar, situated close to the present-day historic centre of Kampen and at the origin of the former river delta of the IJssel. In addition to the cog, two more sunken vessels were discovered at the site during the first diving campaign in 2012: a river barge and a punt-like fluvial cargo vessel. The site had to be excavated as it was necessary to dredge the river for a large-scale restructuring programme initiated by the Dutch Ministry of Infrastructure and Water Management.

After extensive preparations, the excavation started in the autumn of 2015 carried out by a consortium of three companies: ADC ArcheoProjecten¹, Baars-CIPRO², and HEBO Maritime services³. After recording and lifting, the three shipwrecks were transported to a purpose-built conservation and

research centre in Lelystad (Batavialand) (Fig. 2). The project continued with documentation and hypothetical reconstruction of the shipwrecks (Waldus, 2018). The IJsselcog is currently subjected to PEG conservation, which will take at least six years, after which exhibition of the vessel is planned in Kampen.

This article provides an overview of the most important aspects of this project with emphasis on the shipbuilding characteristics of the IJsselcog. The central research objective was to reconstruct the vessel and calculate the nautical stability characteristics based on the 3D model. This article aims to contextualize and explain the process of excavation and reconstruction as a basis for the final results and the interpretation. The first two sections provide the context of the site and the excavation techniques. Then the construction of the IJsselcog is described. Next the process of developing a 3D reconstruction and a virtual floating hypothesis of the IJsselcog is discussed. The virtual floating hypothesis focuses on the static stability of the vessel within its reconstructed maritime transport zone. The resulting nautical calculations are then compared to the results of other known cog reconstructions and replicas. In the conclusion the project is evaluated and suggestions for future comparative research are made.

The site

Archaeological evidence has made clear that the town of Kampen was founded in the second half of the 12th century on the left bank of the river close to its



Figure 1. Location map of the cities and rivers referred to in this article. The site of the IJsselcog is marked with the wreck symbol (ADC).

exit point in the former Zuiderzee (Jager, 2015: 69). In the 13th century and well into the second half of the 14th century, the river was navigable by seafaring vessels like the cog. Kampen flourished as a centre for maritime cargo ships due to its strategic position on the river route from the Rhineland to the Baltic and was periodically a member of the Hanseatic League (Fig. 3).

At the beginning of the 15th century this changed significantly, due to two factors. Firstly, ongoing deforestation in the upper regions of the river catchment-area resulted in increased sediments in the river. Secondly, the devastating St Elisabeth-day floods in November of 1421 and 1424 created the Biesbosch area, an inner tidal area south of Dordrecht (The Netherlands), which substantially shortened the length of the river Waal. This resulted in a gradual decreased flow of water into the Rhine and IJssel and consequently in the siltation of the river delta north of Kampen (Cohen *et al.*, 2009). In the first half of the 15th century it was apparent that water management was required to secure the future of Kampen as a maritime mercantile centre. The wreck-site of the IJsselcog can be placed in this context.

The year of construction of the cog has been dendrochronologically dated between 1415 and 1420, the barge to 1420, and the punt to 1435 (Waldus, 2018: 139). Based on the maritime context and the position of the wrecks in the riverbed, it is assumed that the cog and the two smaller river vessels were deposited around 1450 to change the river current and to close off one of the river branches in the delta.

The depositional processes relating to the wreck-site may be clarified and explained by analysing the



Figure 2. Lifting the IJsselcog, 10 February 2016 (ADC).



Figure 3. Contemporary impression of the Hanseatic town of Kampen and the IJsselcog in 1450 (with permission, A. de Lange, 2017).

local maritime environment. The position of the wrecks in relation to the old river system was verified using data from a LIDAR height model combined with actual multibeam sonar data from the riverbed. It shows beyond doubt that the IJsselcog was located with its stern pointing towards a submerged medieval riverbank, in a position where a gully branches off the IJssel (Fig. 4). This formerly unknown river arm was named the Brunneperdiep after the adjacent modern suburb. The orientation and exact position of the Brunneperdiep could additionally be reconstructed on the basis of a historical map from 1832. It discharged its water originally in the *Zuiderzee* and was 90m wide. The three wrecks together formed a 30m-wide obstacle in the waterway, orientated at right angles to the direction of the current.

Since the reconstructed height of the IJsselcog is 6–7m and the water depth of the IJssel was no more than 3.5m (2 fathoms), the hull of the cog protruded from the water after deposition. As could be observed by the different levels of sand and clay inside the IJsselcog, sediment was used to fill the hold to keep it in position. The cog was found listing to starboard, against the direction of the river current instead of having been tilted sideways by the river current itself (Fig. 5). Geological cores from the surrounding riverbed showed that the current created erosive gullies upstream, against the sides, and around the stem and sternposts of the IJsselcog. This process of erosion is the reason why the shipwreck gradually sank into the riverbed down to the Pleistocene layer. Over the centuries the wreck even adopted the shape of this hard surface of sand and peat. The scarf between the

keel plank and the stern-hook was the fulcrum of deformation of the aft part of the ship: the stern-hook gradually turned almost 90 degrees while the planking remained intact. The stem detached and the planking of the bow opened up.

Despite the IJsselcog sinking into the riverbed, fishermen from later generations frequently lost their fish nets to protruding parts of the shipwreck, as illustrated by the abundance of net weights found on the site. Attempts were made in the past to remove the obstacles with grappling anchors since these were found as well (Fig. 6). The high side of the tilted wreck (the portside), is substantially deteriorated, and during the excavation, some of the portside construction elements were found further downstream. The presence of an anchor stone suggests that the wreck-site was marked by a buoy; however, none of the available historical maps dating from the 16th century onwards, mark the wreck. The IJsselcog was erased from memory, until a survey ship produced a sonar image in 2009 showing the contour of a large shipwreck.

Excavation and raising the vessels

In the murky waters of the Dutch river delta, complex circumstances make archaeological endeavours challenging. Visibility of approximately 0.5m and strong currents constrain the archaeologists in their options for recording archaeological sites. Above all, the river IJssel is now a commercial shipping route; the authorities demanded that during the 5–6 months planned for excavation and raising the vessels, nautical traffic was not hampered in any way.

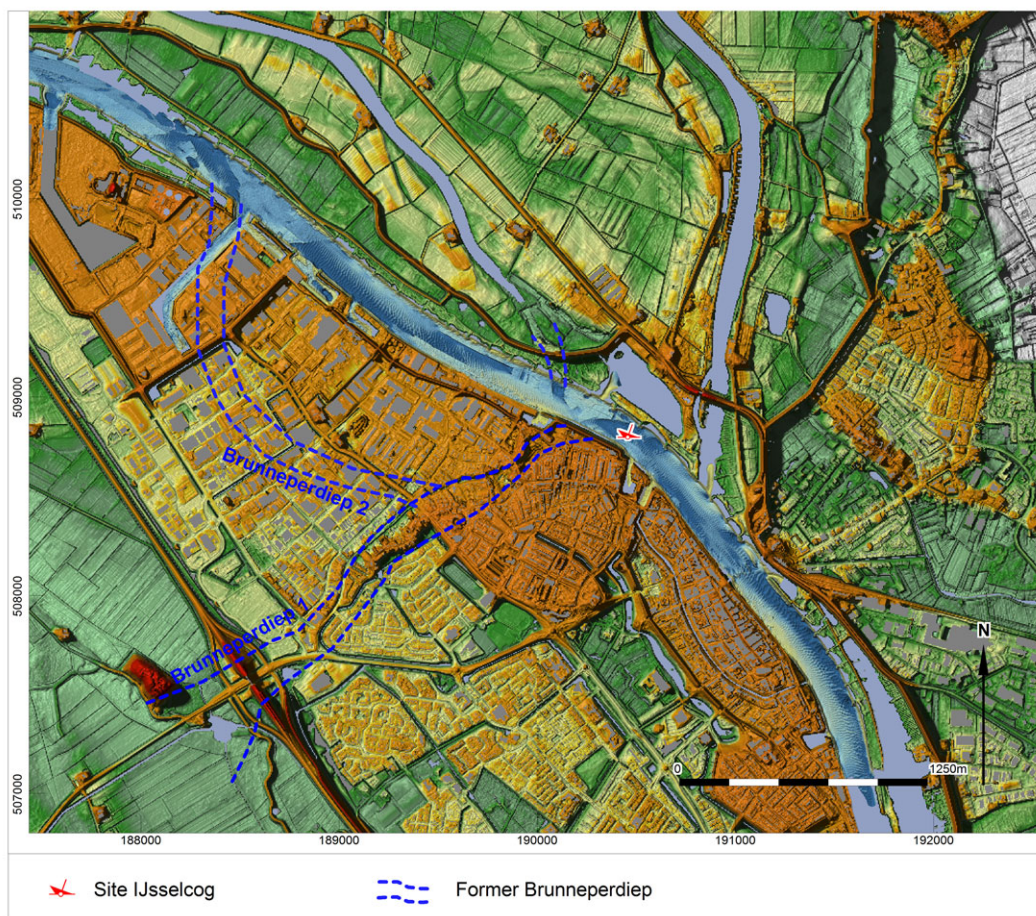


Figure 4. Combined multibeam and digital elevation map of the site and the former river delta of the IJssel at Kampen, showing the position of the shipwrecks in relation to the former landscape (ADC).

A custom-made combined lifting frame and water shield was constructed (Fig. 7), taking the safety of working conditions into account, dimensions of the wreck, and to ensure minimum obstruction to the shipping route. A 200-ton crane ship was deployed to mobilize this construction. It was designed to fit exactly over the wreck of the IJsselcog and small holes in the shield decreased the river flow to create relatively favourable working conditions for two divers with surface-supplied-air diving equipment. During the excavation of the two other shipwrecks the installation was positioned over their location. As the working depth was only 5m, there was no limit in dive time. With an average team of two simultaneously working divers, up to 700 dive-minutes could be achieved in an operational day. The excavation team included underwater archaeologists, technical divers, non-diving nautical archaeologists, surveyors, a specialist in photogrammetry, and the captain of the working vessel with crew.

The divers employed suction pumps to excavate the site. The recording strategy relied on high-resolution multibeam data, acquired by a small survey ship

continuously present at the site. After data processing, archaeological features were labelled in a GIS. For detailed recording of construction features and finds, photogrammetry was used. To deal with the low visibility, features and finds were filmed with an underwater HD camera, after which a selection of frames was processed. Adobe Lightroom was used for this purpose; this software is capable of filtering out most of the sediment reflections that blur the imagery. The next step was to make 3D models in Agisoft. The success of this method under adverse conditions is best illustrated by showing the detailed underwater record of the galley in the IJsselcog, where the remains of a dome oven made of bricks were present (Fig. 8).

A three-step process was developed to lift the IJsselcog from the riverbed. First, a supporting framework was positioned over the shipwreck. Next a supporting structure inside and around the hull was engineered to lift the cog into the frame. Finally, frame and wreck were lifted together using a 200-ton crane. The most difficult part of the process was placing the supporting slings under the cog. Since the riverbed

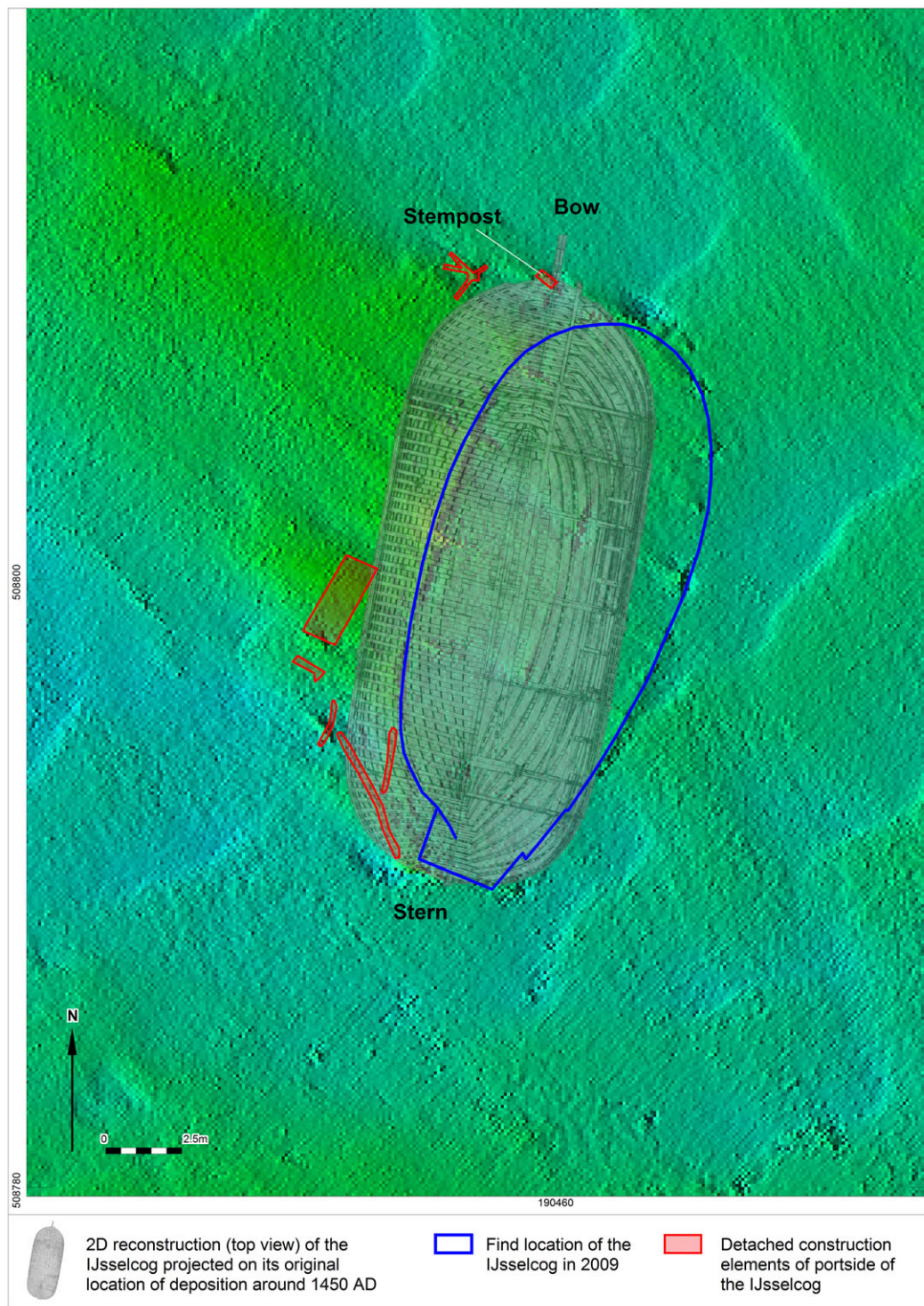


Figure 5. Original position of the IJsselcog at the moment of deposition plotted on the multibeam image of the site to illustrate wreck formation processes (ADC).

consisted of fine sand, it was not an option for divers to excavate tunnels under the cog. To slide the slings under the shipwreck, a rigid circular steel lance with a 10m diameter was designed. This lance was connected

to several water pumps: the one connected to the lance point had a 10-bar capacity and was used to excavate a tunnel under the cog. Other pumps were connected to the several perforated compartments of the lance.



Figure 6. Grappling anchors found inside the IJsselcog (ADC).

This created a continuous water flow, thus preventing the lance from getting stuck in the subsoil. The lance was lined up in a custom-made steel frame and driven by electro motors. The slings were fastened inside the lance and driven into the subsoil under the wreck. Once the other side was reached, they could be disconnected by divers and tied to the lifting frame on the other side. The supporting structure of the cog finally consisted of 40 slings on two levels and five custom-made internal supports. Delicate wooden construction elements were reinforced with screws and planks. To prevent their collapse, some of the construction elements of the wreck were recorded and dismantled prior to the lifting operation. To compensate for the compressing force of the slings, steel bars were placed in between them. With all slings attached to electro motors the cog was lifted from its original position. The forces applied to the slings were controlled by custom-made software. The crane of the working vessel lifted the IJsselcog, and after almost 600 years the IJsselcog broke the surface of the IJssel once more. The entire structure was placed on a pontoon, where the hull was reinforced and prepared for transportation to the purpose-built conservation laboratory at Batavialand (Lelystad).

***Ex situ* recording**

The wreck as raised did not provide the original form of the IJsselcog. It is in a relatively complete but distorted and partly decomposed state, due to the site-formation processes as described above and the necessity to dismantle parts of the hull during the excavation process. It was intended to make complete reconstruction drawings of the IJsselcog. All of the dismantled elements of the ship were recorded by hand during the excavation process. The IJsselcog was recorded using the method of 3D photogrammetry and by systematically gathering the measurements of individual construction elements in a database. The data was used to create longitudinal and transversal reconstruction drawings of the ship over the keel (centreline) and at the seven through-beams. These sections were later used to reconstruct top plans and side plans. By carrying out recording and the reconstruction work simultaneously the research team was stimulated to discuss interpretations made of deformed and incomplete parts of the hull construction. The final product of the documentation and reconstruction phase was a database of all dismantled timbers and a reliable set of 2D reconstruction drawings.

The dataset was then used to create a digital reconstruction model in the 3D program Rhinoceros. This in turn was used to make nautical calculations and to compare the IJsselcog model to other 3D models of medieval cogs, such as the Bremen cog (Figs 9 and 10).

Construction of the IJsselcog

The hull of the IJsselcog was 70% complete when lifted from the river bottom, including detached elements that were lifted during the excavation (Fig. 11). Damage was concentrated at the portside and the stem; half of the portside and the upper part of the outer stem was detached, resting in the riverbed. The planking to starboard was complete, with the exception of the sheer strake. The superstructure was lost, although a few supporting beams were found in and around the wreck. Here follows a description of the construction as it was documented *in situ* and *ex situ*. Since it was decided not to dismantle the ship, it has not been documented at elemental level. Ship terms used are taken from Steffy's illustrated glossary (1994).

The backbone of the ship is a 10.25m-long keel plank in one piece, with knee-shaped hooks attached fore and aft. The keel plank is 0.32m wide by 0.13m high. The total length of the keel with the scarfed knee-hooks attached is 16.05m. The forward knee-hook has a horizontal length of 3.7m at the underside. The keel plank is fixed onto the tapering flat scarf of the knee-hook with a 1.0m overlap. The knee-hook aft has a horizontal length of 2.2m on the underside. It is fixed onto the tapering flat scarf of the keel plank that is 0.68m long. The knee-hooks support inner and

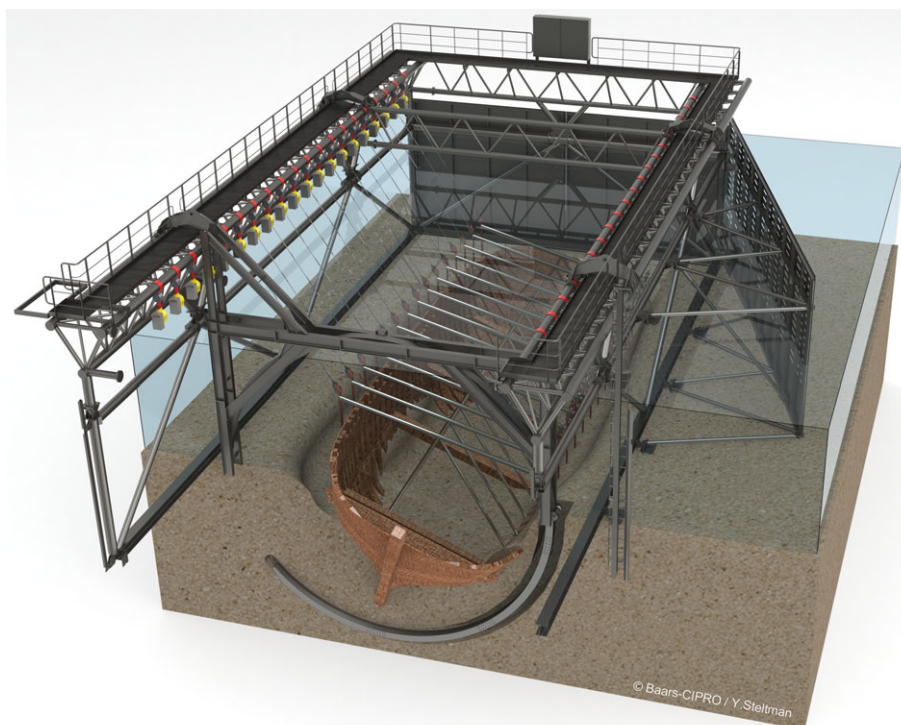


Figure 7. The design of the custom-made iron lifting frame and water shield (Y. Stelmaan, Baars-CIPRO).



Figure 8. The galley of the IJsselcog recorded by underwater photogrammetry (UBI3D, T. van Damme).

outer stem and sternposts, which are both straight timbers. The sternpost is preserved over a length of approximately 3.5m. The ship was outfitted with a rudder as indicated by two supporting metal braces attached to the sternpost. The rudder itself was not

recovered, but it must have been 0.08m thick near the sternpost. The stem is preserved over a length of 1m. The outer stem, found detached in the riverbed, adds another 4.4m to this length. Stopwaters were observed in the scarf between the inner stem and knee-shaped

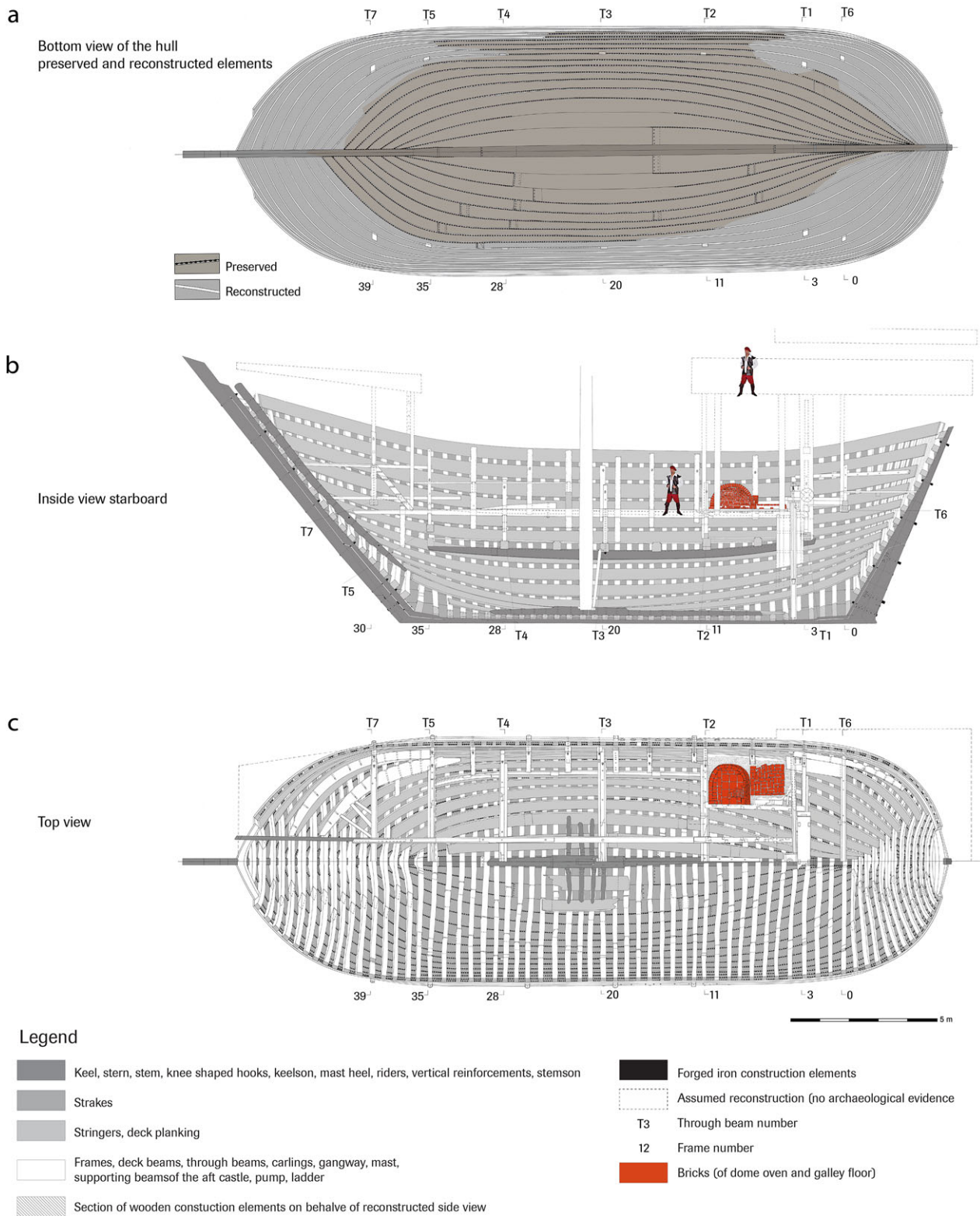


Figure 9. Three 2D reconstructions the IJsselcog: a) the preserved and reconstructed hull; b) view of starboard inside; c) top view (K. Vlierman/ADC).

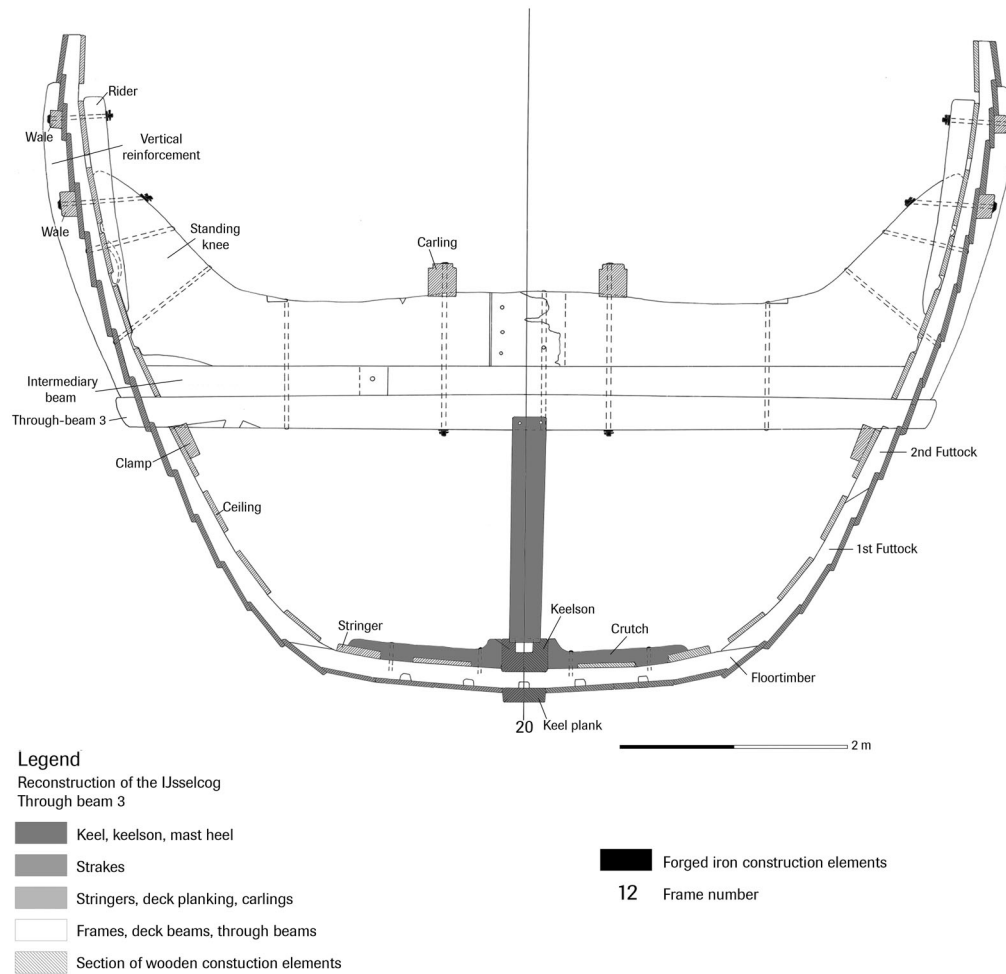


Figure 10. S section at through-beam 3 (K. Vlierman/ADC).

hook, as well as in the lower scarf between inner and outer stem. They interrupted the water flow along the scarf to protect these timbers. Both outer stem- and sternpost are fastened to their respective inner posts using iron bolts.

The first three strakes of the bottom amidships are carvel built. The remaining part of the shell consists of 15 plank strakes and is lapstrake built. Near the stem and sternpost, the hull is lapstrake from top to bottom. The three flush-laid bottom plank strakes gradually overlap each other towards both ends of the vessel. The port planking of the hull was preserved up to the 10th strake, the starboard planking is complete up to the 17th strake. The missing 18th strake is the sheer strake, as deduced from an imprint on the top framing timbers and their shape. The planking is tangentially sawn from oak logs with two to four planks in each strake run, and has a thickness of 0.04m. The planks in one strake are interconnected with flat, 0.40m-long, diagonal scarfs, using two vertical rows of double-clenched iron nails, 0.30–0.34m apart, with four nails in a row. The lapstrakes are joined using an estimated

minimum of 6000 double-clenched, forged iron nails. The lands are generally 0.05–0.07m wide.

The hooks and inner stem and sternpost are rabbeted to receive the garboard strakes and the next five strakes. The strakes higher up are nailed to the outside of the stem and sternposts.

The hull was made watertight by caulking all joints and seams on the inside and outside with packed moss under half-round laths, held in place by sintels (iron cramps). The average distance between the sintels is 0.6m, from which can be estimated that the ship construction used almost 23,000 sintels of Vlierman's type E (1996: 82).

Repairs were observed all over the hull both inboard and outboard. Specific concentrations of repair patches have not been identified. In most cases cracks along the grain in the planking were caulked with packed moss under a half-round lath, held in place by sintels every 0.06–0.07m (Fig. 12). In order to pack in enough moss, the cracks were widened and cut into a V-shape. The cracks varied in length from 0.10–2.40m, and in some cases provided the construction sequence as several

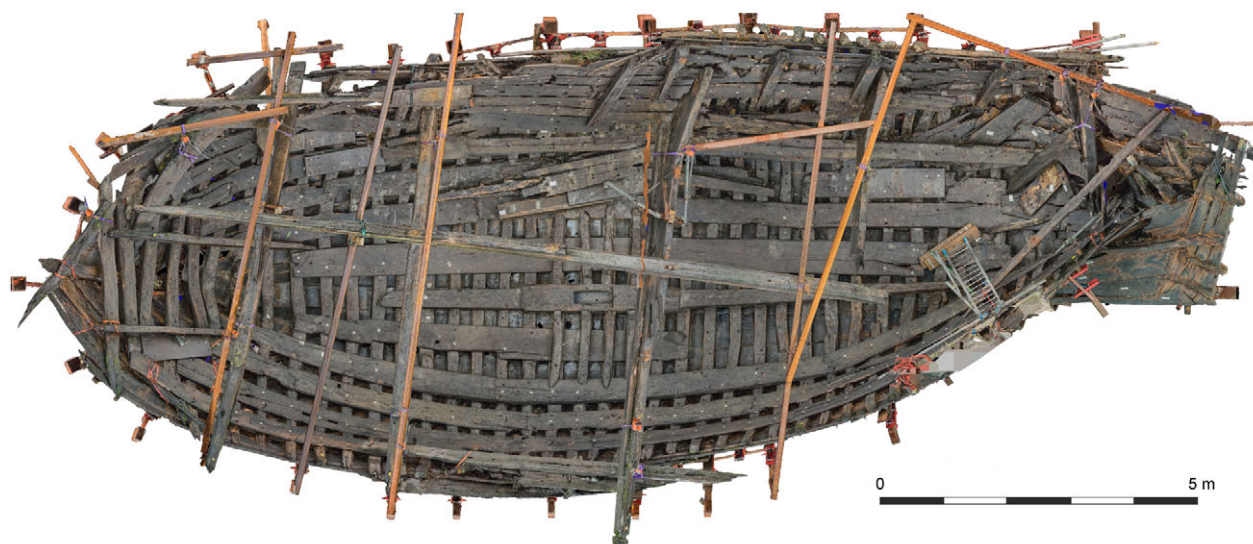


Figure 11. Photogrammetric image of the IJsselcog in the conservation laboratory in Batavialand (Lelystad) (UBI3D, Thomas van Damme).



Figure 12. Repair of the ship's hull at the portside stern (ADC).

repairs were made before the framing was put in place. Some sintels of Vlierman's type E1 were also found (Vlierman, 1996: 82), suggesting other repairs were made later in the operational phase of the vessel. In some cases, small planks were used to cover damaged or broken planking. These tingles were attached with iron nails, some before the futtocks were positioned. If the damaged area was too large, it was cut out and replaced by an inlay, as observed in the second ceiling plank at the portside.

The reconstruction drawing includes 67 frame stations of which 43 frames were found in position (Fig. 9). The room and space are 0.43–0.45m. There is no clear difference in spacing when comparing the bow and stern frames to the frames in the middle.

The position of the futtock scarfs could not be fully documented because they are covered by ceiling planks. They seem to be located generally between the 7th and 10th strake.



Figure 13. Aft pump basket, top view (ADC).

The floor-timbers are V-shaped at frame stations 0–11 in the aft section. The floor-timbers of frames 12 and 13 transition from a V to a flat shape. Near the bow section, frame stations 32 to 38 are also V-shaped, but are flat by frame station 42. The floor-timbers measure around 0.18–22m moulded and 0.15m sided. The scarfs joining the frame timbers are 0.20–0.36m long. The floor-timbers were fitted after the positioning of the bottom strakes. Some wooden spike plugs were observed proving the use of construction cleats to hold the bottom planks together until they could be fastened to the floor-timbers. Initially one iron nail per strake was used as a temporary fastening. For final fastening two treenails per strake were driven through the strakes and floor-timbers.

At the base of the floor-timbers, trapezium-shaped limber holes were cut and aligned to form a watercourse ending fore and aft in pump wells (Fig. 13). More watercourses run along the centreline of the keel and along the edges. Some remains of both pump systems were still in position. Small laths roped together were probably used as sweepers to prevent clogging in the watercourse. A number of these laths were found in the stern on the bottom of the wreck.

A keelson with a length of 9.2m is notched over the floor-timbers between frame station 7 and 29. The keelson widens between frames 18 and 24 to accommodate a mast step. At the mast step the keelson is 0.40–0.43m sided and 0.28–0.30m moulded. It is supported on each side by four crutches or mast-step buttresses attached to the ceiling. The ceiling is open, meaning that the 0.40–0.50m wide ceiling planks are positioned on top of the frames with spaces of at least 0.10m between them. Twelve ceiling planks are

preserved more or less in position, of which nine are on the starboard side. Twelve stringers per side were originally present. The thickness of the ceiling planks is 0.04m, except for the bilge ceiling plank or stringer that measures 0.06–0.08m.

A longitudinal timber, attached with treenails to the 6th ceiling strake up from the keelson has a thickness of 0.12m and recesses are cut 0.02m deep into the topside to support the through-beams at the level of the 10th strake. This clamp provides evidence for the division of the hold. In between the recesses cut for the through-beams, recesses for the inlay of a level of deck beams are observed. These deck beams were found during the excavation in the hull of the wreck and support the idea that the hold was divided in two levels.

Another longitudinal internal strengthening construction are two inner side stems or stemsons in the ship's bow. This is a common construction in the larger cog-like cargo vessels like the Doel 1 cog and the Bremen cog.

The transversal strength of the construction was improved through the use of seven or eight through-beams at two and possibly three levels (Fig. 9). Five through-beams were found more or less intact and their original position was established during the reconstruction phase. Beam 1 is positioned at frame station (FS) 3, beam 2 at FS 11, beam 3 at FS 20, beam 4 at FS 28, and beam five at FS 35. These through-beams protrude through the 10th strake on both sides of the hull. The find of two detached standing knees suggests that two additional through-beams were originally present. Based on the reconstructed hull shape, they most likely protruded through the 12th strake: beam 6 at FS 0, and beam 7 at FS 40.

This through-beam construction was observed on the starboard side with through-beam number 3. The through-beam is supported by the aforementioned clamp, but also rests on the flattened butt-end or head of the first futtock. The foot of the second futtock rests on the through-beam. The beam ends are notched to fit the enclosing strakes. The joints are subsequently caulked with moss to ensure watertight integrity. Softwood fairings were attached to the front side of the outboard beam ends. Five cone-shaped pieces of wood were found on site, interpreted as fairings, placed to absorb shocks and prevent materials such as ropes from getting caught by the outboard beam ends. With the beam ends submerged while sailing, the fairings may have served to streamline the hull. The maximum length of these fairings was approximately 1.5m.

The hull is reinforced by several additional construction elements. Remains of vertical and horizontal reinforcements were observed on the starboard side and could be reconstructed as follows. Two horizontal reinforcements are attached to the outboard of the 14th and 16th strakes, running the full length of the hull and are interpreted as applied wales (Fig. 10). These timbers provide longitudinal strength and protect the hull from damage through impact, just as in a flush-built ship. Thirteen vertical reinforcements, or riders, are connected inboard over the ceiling planks and outboard over the wales (Fig. 10). They serve to increase the transversal strength of the upper part of the hull. The riders are connected to the wales by heavy, forged iron bolts. This construction gives the wales extra strength and support for the standing rigging near the mast. Nine shroud irons with deadeyes attach the nine stays of the central mast via the wales to the ship's structure, as observed on the starboard side. The shroud irons have a diameter of 0.03m, run through both wales and are fixed to the lower one.

The internal structure above the through-beams includes two standing knees. Above through-beam 3 (0.30m moulded) there is an intermediary beam (0.26m moulded), on which the two standing knees are placed and fastened with treenails (Fig 10).

The longitudinal strength of the IJsselcog is improved by two carlings, or longitudinal deck beams, that rest on the standing knees. They line up with the two stemsons mentioned above. Additionally, short carlings run parallel to the main carlings to support the deck planking. Only at the galley, where the upper deck was preserved, a short carling was found *in situ*. Others were found during the excavation in the hull and their original position was later reconstructed. The same counts for a foundation post of an aft castle, which was found at starboard outside the wreck.

There are some clues that help outline the main deck construction and layout in the stern. In the zone between through-beams 1 and 2, on the starboard side, part of a slightly sloping deck was still in place. This is also the location where a galley with a dome-shaped

oven and fire pit was found. The planks of the deck were sawn from Scots Pine (*pinus silvestris*). In between through-beam 1 and the projected upper through-beam 6, fragments of another deck with a length of 1.3m were present. This deck was approximately 0.20m higher and housed a windlass. A windlass drum was found in the stern section of the shipwreck (Fig. 14). Also, a heavy beam was found in the same section with notches indicating a function as a windlass cheek. The windlass must have been employed to handle the yard-sail combination.

Almost 0.50m higher than the windlass deck, a third deck was situated in between the projected upper through-beam 6 and the stern. This was probably the helmsman's deck. The planking orientation of the two small decks in the rear is longitudinal. The planking orientation of the main deck was transversal. Notches were found in the carlings to secure the planking. There was no evidence of nails being used to fasten the deck planking to the beams.

Two inboard hull reinforcement planks were found in the shipwreck, out of position, at the starboard side. One plank in the stern section is 4m long, 0.20m wide and 0.12m thick. The other plank is found in the bow section, 5m long, a maximum of 0.47m wide, and 0.10m thick. Because of their unique shape that marked the form of the hull, these planks were essential for the reconstruction process. They were horizontally fastened to the ceiling and futtock construction with treenails, as a waterway would be attached. During reconstruction, the position of these planks matched the hull shape about 0.5m above deck level. Other than having a function as hull reinforcement planks, their suspended position is not yet explained. The distance to the top strake may have been too large for an average height person to peek over the side.

There are indications of the existence of a superstructure in the stern, possibly a castle-like construction. A few large beams found detached from the vessel could be interpreted as support for this superstructure on the basis of rabbets and the position of probable treenail holes. Any attempt to reconstruct the superstructure unfortunately is bound to be hypothetical.

Inside the wreck a number of specific structures survived, which give insights into the function of the ship itself. As mentioned above, a surprisingly intact oven area was found in between through-beams 1 and 2. The oven floor is built on top of three layers of planking. The first layer consists of transversal deck planking. A second transversal plank layer and a third of longitudinal planks make up the furnace box structure. The fact that the construction was not fixed to the ship by treenails or iron nails, is an indication that the oven was an improvised construction installed in a later phase of the ship's life. On top of the three planking layers, three flagstone layers were stacked as a basis for circular layers of red bricks (each 0.32 × 0.15 × 0.08m) forming a dome. Next to this oven, a



Figure 14. The drum of the windlass (UBI3D, T. van Damme).

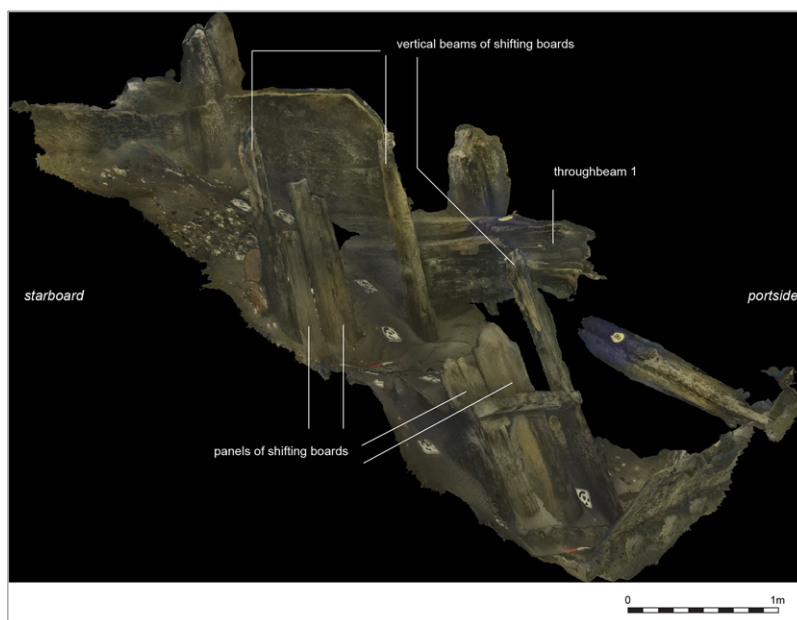


Figure 15. Photogrammetric underwater recording of the shifting-boards in the stern of the IJsselcog (UBI3D, T. van Damme).

fireplace was present. Remains of a grill found in this area might be an indication that the fireplace was used for the preparation of meat.

Next to the fireplace towards the stern of the ship, part of a rectangular wooden pump tube remains with a cross-section of $0.20 \times 0.16\text{m}$. In this position at the bottom of the ship, close to the keel, the remains of a pump basket, a pump spear, and fragments of leather were found. In the same position on the port side of the keel a fairly intact pump basket survived (Fig. 12).

In the stern, wood panelling was preserved between through-beams 1 and 2 (Fig. 15). Three panels were fixed longitudinally with small vertical beams held together with crossbeams onto which three pine wood planks were attached. Iron nails are used for fastening the panels to the vertical beams. The panels are interpreted to be shifting-boards, preventing the cargo moving and causing instability.

In the area around the mast step the remains of a removable or false ceiling was found. It consisted of longitudinal timbers, placed on the first and second ceiling strakes and covered with loose planks and dunnage (Fig. 16). *Salix* twigs, branches, and straw were

abundant across the whole width of the false ceiling. This construction would have kept the cargo dry by separating it from accumulating bilge-water and, at the same time, covering the open space between the floor-timbers. The false ceiling and the remains of what were probably shifting-boards in the rear of the ship are indicators for the internal layout of cargo space. It is plausible that the cog was able to carry a load of casks amidships for which a dry, horizontal, upper cargo deck was reserved. The shifting-boards in the rear could have contained sacks of merchandise, such as grain.

The general construction characteristics of the IJsselcog can be summarized as follows: The basis of the vessel is defined by a keel plank. It has straight stem and sternposts connected to the keel with knee-shaped stem and stern hooks. The bottom is carvel built and the sides are lapstrake. The stem and sternpost are rabbeted to take the garboard, but not the keel plank. The hull was constructed with 18 strakes on each side. The ship was constructed with at least five and possibly eight through-beams to improve transversal strength. The hull was made watertight using a variety of types of moss caulking, half-round laths, and sintels. The strakes

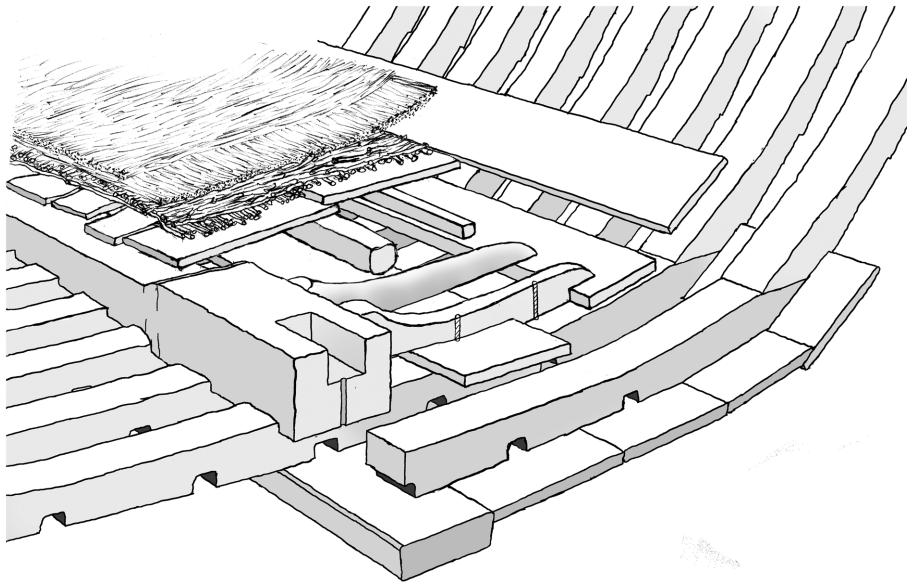


Figure 16. The (false) cargo ceiling (reconstruction drawing in perspective by G. Dijkstra, ADC).

were joined using double-clenched iron nails. The vessel only used one mast for sailing. The combination of these traits defines the wreck in archaeological terms as a cog-like ship.

Unique to this cog find is the use of riders and applied wales to strengthen the relatively high freeboard. The wales were connected with iron bolts to the 14th and 16th strakes of the hull. These construction traits are generally applied to flush shipbuilding, but have not previously been observed in cogs. The main deck was positioned on top of the standing knees and the carlings. Evidence for a deck that divided the hold was found in the form of recesses in the clamp that might have supported deck beams. Due to favourable preservation, relatively delicate and rarely found construction elements were present, such as the shifting-boards in the stern and the false ceiling in the middle of the hold.

The 3D reconstruction

The process of reconstruction of the IJsselcog started with 2D paper reconstruction drawings at a 1:10 scale using the photogrammetric record as the basis of exact measurements of all structures and loose timbers. Longitudinal and cross-sections based on exact measurements of the remaining hull served as the starting point of all reconstruction drawings. A total of 13 were made: a longitudinal section over the keel from stem to stern, seven cross-sections at the cross beam positions, a lines plan, an inboard view of the starboard side, an outboard view of the portside, and two plan views: one with the complete inner construction and one without, just showing the planking of the hull (see <http://project.archeologie.nl/4170214>).

The drawings have been digitized using Rhino 3D software with a 300 dpi resolution. At a 1:10 scale this resulted in about one pixel per mm in real (ship) dimensions. The high-resolutions scans were unworkable with the Rhino 3D software due to their size, so for the 3D reconstruction all drawings had to be reduced to a more practical 127 dpi, which results in one pixel per 2mm in real (ship) dimensions. With an average line thickness of 3–4 pixels the minimum precision of the drawings was about 8mm in real dimensions.

The longitudinal section and the cross-sections of the ship were used for the first 3D line reconstructions. On average, alignment errors between the cross-sections and the side view were in the order of 0.06–0.08m (real dimensions) and errors with the top view could range up to 0.20m (real dimensions). These errors occurred mainly around the bow and stern as the shape of the IJsselcog needed to be interpreted there.

For the reconstruction, the drawings were traced to digitize the data. Curved lines were rebuilt as 3rd-degree poly lines to obtain the smoothest lines. The reconstruction has been built from the outside of the hull inward. This approach was chosen in order to obtain a realistic hull shape needed for the virtual floating hypothesis. In this process the realization of the planking was the most challenging as the shape of the upper planks around the bow and stern are mostly interpreted and, above all, the bending and twisting of the lower hull planks made 3D modelling complex.

To manage the complexity of this project the following work process was chosen. First, all planks in the cross-sections were traced and placed in 3D space. Then a rudimentary plank was constructed by connecting the cross-sections (Fig. 17a). During the

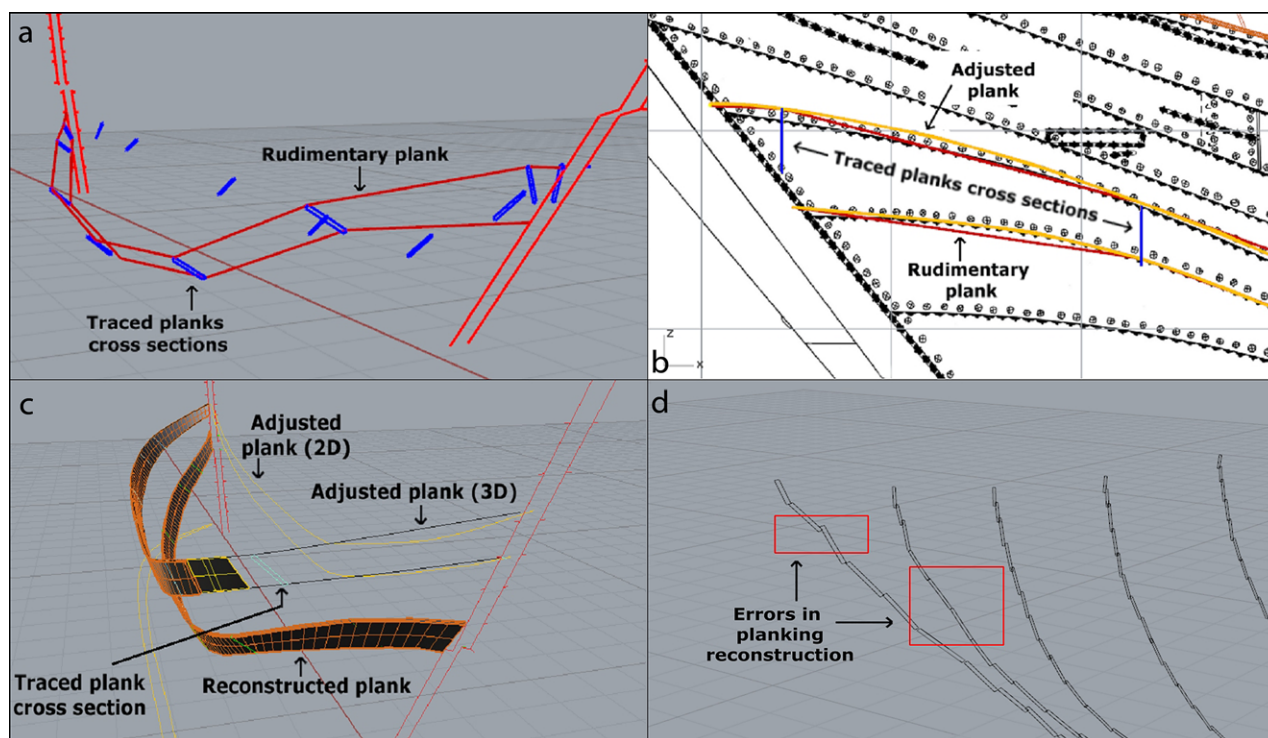


Figure 17. *a*) Example of strake reconstruction indicated by red lines. The blue squares indicate the positions of the strakes at the 2D cross-sections and lineplan; *b*) adjusted strakes based on reconstruction 2D drawing side view; *c*) reconstructed strakes based on adjustments; *d*) example of errors in hull shape and not overlapping planks based on cross-sections of the reconstructed planks (ADC).

next step, the plank was projected on the side and top views and adjusted in such a way that each the plank traces the general form of the planking on the side/top view, but also matches the traced planks of the cross-sections (see Fig. 17b). In this way the cross-sections were used to anchor the plank in 3D while the general shape was provided by the side/top view.

The 2D lines were thereafter projected into 3D space and connected with a surface. An average plank thickness of 0.04m was used to create the hull in 3D (Fig. 17c).

The corrections in step 2 were not precise enough to connect all strakes correctly. For example, partly overlapping planks and a non-realistic shape of the hull occurred (Fig. 17d). By repeating the described process several times, the shape of the hull could be improved. The final hull shape has been determined by the expert judgement of the authors of this article.

The approach described above did not however provide a satisfactory result for the frames.

The shape of the frames was often too complicated, particularly in the areas of the bow and stern, to obtain the correct form and connect the frames to the planking. The process used to obtain a reliable reconstruction of the frames is explained in Figure 18.

Most of the other items of the IJsselcog could quite easily be drawn with the help of the available drawings

without any special techniques. For some items such as the ceiling, a combination of the 2D drawings and the inside view of the frames was used in order to obtain a realistic position. Figure 19 shows the reconstructed hull together with the interior construction. Almost all elements up to the top of the hull could be reconstructed on the basis of the 2D drawings.

Virtual floating hypothesis

Although the upper parts of a ship construction only contribute a small percentage to the weight of the hull, they have a large influence in determining the stability parameters of the ship (Tanner, 2017; 2018). In order to make nautical calculations using the 3D reconstruction as accurate as possible, a similar approach to that used by Tanner (2018) was applied. Three key facts are important to determine how a virtual reconstruction of a vessel floats.

1. The determination of the displacement based on the ship's weight. The weight of the ship could be estimated broadly as about 30% of the ship structure was reconstructed based on the available wreck data.
2. The determination of the centre of buoyancy based on the hull shape: this aspect could be calculated

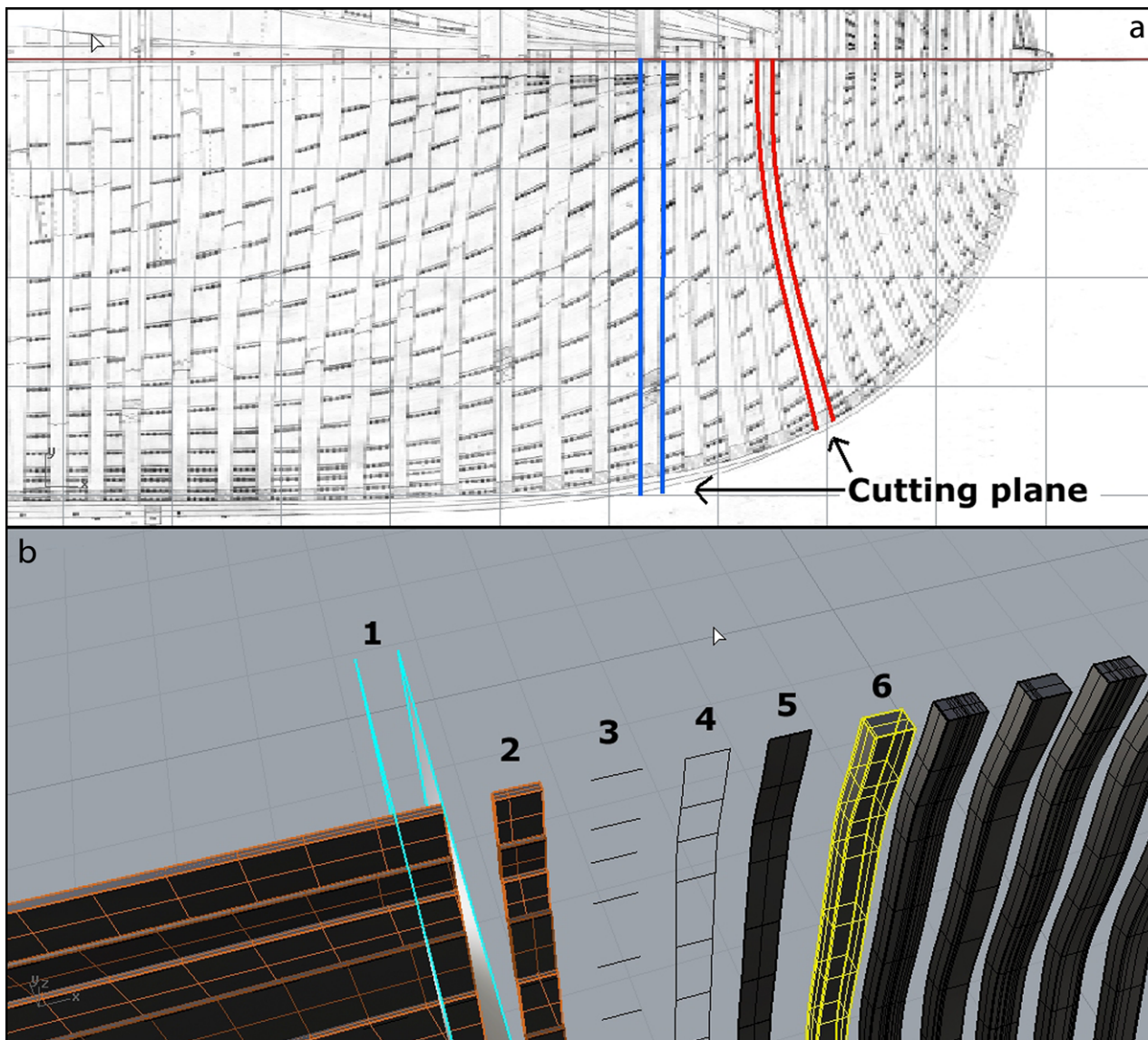


Figure 18. Frame construction of the IJsselcog Skeleton: a) cut plane construction based on the top and side view of the IJsselcog; b) construction of an individual frame in six steps (ADC).

quite accurately as the IJsselcog was sufficiently preserved to make a reliable hull reconstruction.

3. The determination of the flotation trim via the centre of gravity: this parameter was the most difficult to determine as the missing top parts of the reconstructed ship act strongly on the centre of gravity and hence the stability of the ship. Small misalignment errors of the mast, rigging, and castles would result in increased trim errors and unrealistic ballast estimates. It was therefore not attempted to answer this question within the scope of this article. For the virtual floating hypothesis of the IJsselcog a number of assumptions had to be made about certain properties of the ship and the missing top part (such as rigging and castles). As

indicated above, the IJsselcog was mainly built of oak. For the nautical calculations it was assumed that the ship was entirely built from oak. As with the Bremen cog reconstruction an oak density of 800 kg/m³ was used. It is assumed that the IJsselcog only had an aft castle, since foundation posts of a castle were found only in this part of the wreck. For the virtual floating hypothesis, an estimated weight of the castle was determined using data from the Bremen cog. The aft castle of this shipwreck without rigging was determined to be 11.7% of the total weight or 13.4% of the weight of the Bremen cog without a castle. The weight of the rigging was determined in the same way; for the Bremen cog the rigging was 8.7% of the total

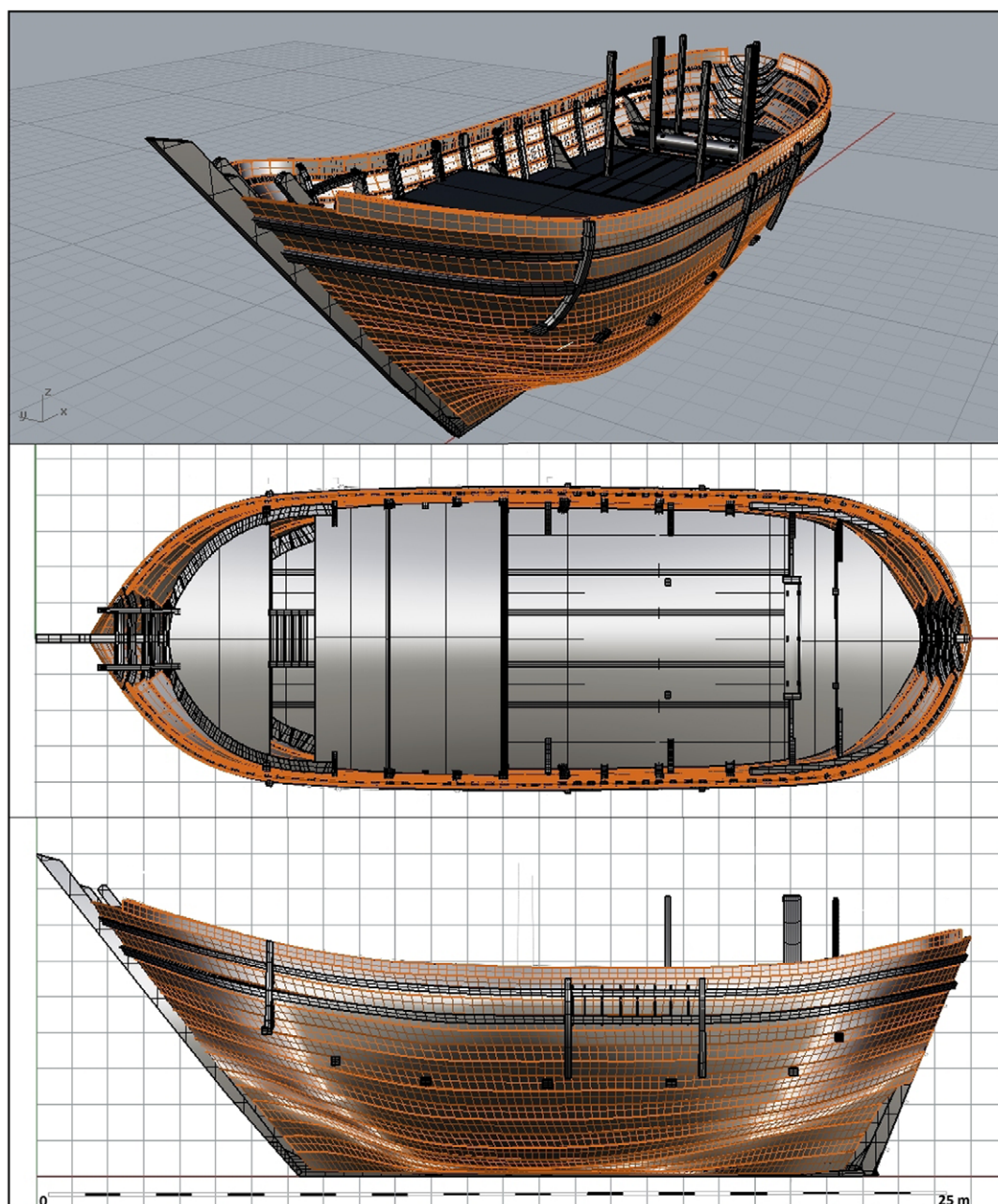


Figure 19. The 3D reconstruction of the IJsselcog viewed from various directions (ADC).

weight of the empty bare hull and castle, or 9.9% of the empty bare hull (Tanner, 2017). The two percentages (13.4% and 9.9%) were used to estimate the weight of the castle and rigging of the IJsselcog. Only the initial static stability was calculated and not the dynamic stability characteristics of the reconstruction. The authors tried to stick as closely as possible to the archaeological and contextual data of the maritime landscape and the site. This implies that the nautical calculations are based on four likely sailing conditions while alternative conditions are conceivable:

1. The Maritime transport zone of the IJsselcog was coastal waters, the Zuiderzee, and IJssel. With an average water depth of 3.5m (two fathoms) and a tide amplitude of about 0.30–0.60m in that region (Schilstra, 1969), a vessel would need to have a maximum draught of 2.5m to be able to reach Kampen. This is more-or-less the height of the through-beams of the IJsselcog as measured from the keel.
2. The hold of the IJsselcog was stowed with casks of meat and sacks of grain. As described above, in the aft part of the IJsselcog remains of

Table 1. Cog characteristics (partly based on Hoffmann and Hoffmann, 2009), Vlierman (forthcoming) and Tanner (2018) of four cog replicas (Kieler cog, Kampen cog (OZ36), Roland van Bremen, and Ubena) and two digital reconstructed cog ships (Bremen cog and IJsselcog). Numbers indicated in *Italic* are estimated by Tanner (2018) and numbers in **bold** are estimated in this study. Other numbers are either measured or calculated. The cargo volume is the total hold volume minus the ballast volume

	Kieler cog	Roland von Bremen	Ubena	Kampen cog (OZ36)	Bremen cog	IJsselcog
Length amidships (m)	23.27	23.27	23.23	20	23.16	26
Maximum beam (m)	7.62	7.62	7.62	7.32	7.68	8.47
Keel length (m)	15.60	15.60	15.60	12.3	15.6	16.05
Mast height (m)	24.00	24.00	23.00	22.4	23.50	26.00
Yard length (m)	18.00	14.60	18.00	13.10	<i>18.00</i>	20.00
Sail area (m ²)	100	90	150	144	<i>100</i>	150-185
Displacement without ballast (t)	32.1	94.1	34.2	45	58.7	78.4
Displacement ballast (t)	22 (stones)	20 (lead)	35 (lead)	25	15 (stones)	~40 (stones)
Draught (no cargo) (m)	1.60	2.25	2.25	No data	1.49	1.46
Cargo volume (m ³)	No data	No data	No data	~100	~135	~61 (upper hold) +76 (lower hold)

shifting-boards were found (Fig. 15). These are interpreted as divisions to prevent bulk cargo from sliding, causing instability. Together with barley chaff found in the sediments between the frames (Waldus, 2018: 302), the panelling has been interpreted as evidence for the transport of sacks of grain. In the centre of the hold, remains of wooden casks were encountered in association with the false floor described above. A large quantity of bovine bones with butcher marks suggest that these casks might have contained conserved beef (Waldus, 2018: 319). Therefore, calculations of cargo capacity are made using the weight and volume of sacks of grain and barrels of meat.

3. The volume of the hold is defined by archaeological evidence for the deck constructions. The archaeological remains of two decks are described and their position is interpreted (Fig. 10). It is assumed that all cargo was stowed under the main deck. Even though the crossbeams might have served as bulkheads, no evidence is found for vertical separation of the hold.
4. The available cargo space of the hold is based on the initial static stability of the IJsselcog with ballast. Even though it is conceivable that cargo might be used as ballast, it is assumed that the cog was originally stabilized using stone ballast. Evidence is provided by a small quantity of stone boulders found in the hold.

Before applying these conditions to the nautical calculations, a short overview of equivalent data from four replicas of cogs and the digitally reconstructed Bremen cog were compared with the reconstructed characteristics of the IJsselcog (Table 1). This comparison serves to fill in or estimate data missing from the IJsselcog. The height of the mast and the size of the yard have been estimated to be 10% larger than the Bremen cog in order to compensate for

the increased size of the hull. The size of the sail area was the most difficult to estimate as the values differ substantially for the different ships. In order to compensate for the increased weight and the ship's cross-section in the water, the sail area was estimated to be in the upper limits of those proposed for the other ships.

On average the IJsselcog is about 10% larger than the other cog-like cargo vessels and about 160–200% heavier than the other ships. (*Roland von Bremen* is not included as its weight is excessive for its size and not representative for the weight of ships around AD 1400–1500).

In order to determine the centre of buoyancy, a series of hydrostatic calculations was performed using Orca 3D software. For that purpose, the cargo area was attributed increasing weights up to a limit of about 1000kg/m³, which is equivalent to the weight of cobble stones often used as ballast.

Table 2 gives an overview of the results. It shows that the centre of buoyancy gradually lowers with increasing weight and draught. The increased weight does not have much influence on the centre of buoyancy in the longitudinal or traverse direction. The same is true for the trim of the ship, which is hardly influenced at all.

The results show that broadly 40 tons of ballast is needed to stabilize the IJsselcog (Table 2). With a ballast density of about 1000kg/m³ this would require about 40m³, leaving 137m³ for cargo (Fig. 20). The increased size does not seem to correspond with an increased cargo load as the volume of the hold for cargo is comparable to the Bremen cog, due to the need for additional ballast.

Keeping the through-beams above the waterline (Fig. 21) an additional 60 tons of cargo (Table 2) could be transported. A load of casks (300 large casks of 0.5m³ + 329 small casks of 0.08m³; Fig. 19) of meat (591kg/m³) is equivalent to a weight of around 67 tons. A load of sacks of grain (791kg/m³) would be

Table 2. Overview of the hydrostatics calculations of the reconstructed IJsselcog with increased weights. LCB, TCB and VCB indicate here the longitudinal, transverse and vertical centre of buoyancy. Trim indicates the alongside rotation of the ship and Ax and WSA indicate the wetted cross-section and wetted surface area. Finally, GMt indicates the stability of the ship. Positive values indicate a positive stability

Weight ship (kg)	LCB (m)	TCB (m)	VCB (m)	Draught (m)	Trim (°)	Ax (m ²)	WSA (m ²)	GMt (m)
78,486	14.62	0.00	4.42	1.46	0.59	7.5	104.7	-1.2
98,486	14.67	0.00	3.87	1.65	1.09	9.1	118.0	-0.5
118,487	14.70	0.00	3.51	1.85	1.20	10.5	130.3	0.0
138,487	14.73	0.00	3.25	2.06	1.25	11.9	141.4	0.3
158,488	14.74	0.00	3.07	2.26	1.25	13.3	152.0	0.6
178,488	14.76	0.00	2.92	2.45	1.24	14.6	161.9	0.9
198,489	14.76	0.00	2.64	2.64	1.20	15.9	171.5	1.1
218,492	14.74	0.00	2.84	2.86	1.03	17.1	180.7	1.1
238,494	14.72	0.00	2.87	3.06	0.87	18.3	189.7	1.2
258,497	14.70	0.00	2.90	3.44	0.00	19.6	198.4	1.2

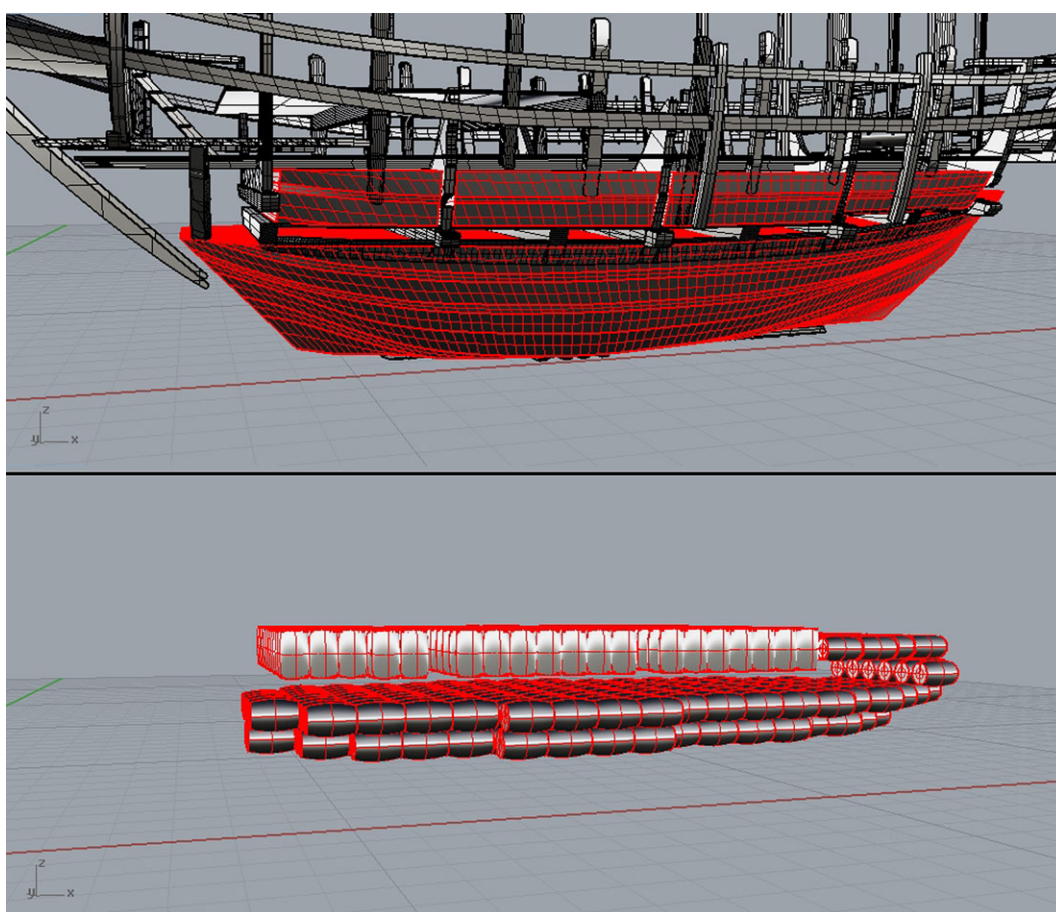


Figure 20. Available cargo space. Top view indicates the available space (in red) in the IJsselcog while the bottom view shows an example of the cargo space filled with casks. The cargo space below the casks would be filled with stone as ballast (ADC).

around 108 tons. The draught for these cargos would be around 2.16m for the barrels and around 2.55m for grain.

According to a medieval Icelandic Law in the Grågás Codex from 1280, the minimum freeboard (F) of a cargo vessel is calculated by the formula $F = 2D/5$, where D is the depth of the hull amidships (Morken,

1980: 178; Tanner, 2018: 66). When this calculation is applied to the IJsselcog, with a hull depth amidships of 5.85m, this would result in a draught of 3.51m, equivalent to 350 tons of cargo. This seems unrealistic as most of the cargo would be stored above the main deck and the draught would have been too deep at least for the IJssel river. These calculations suggest

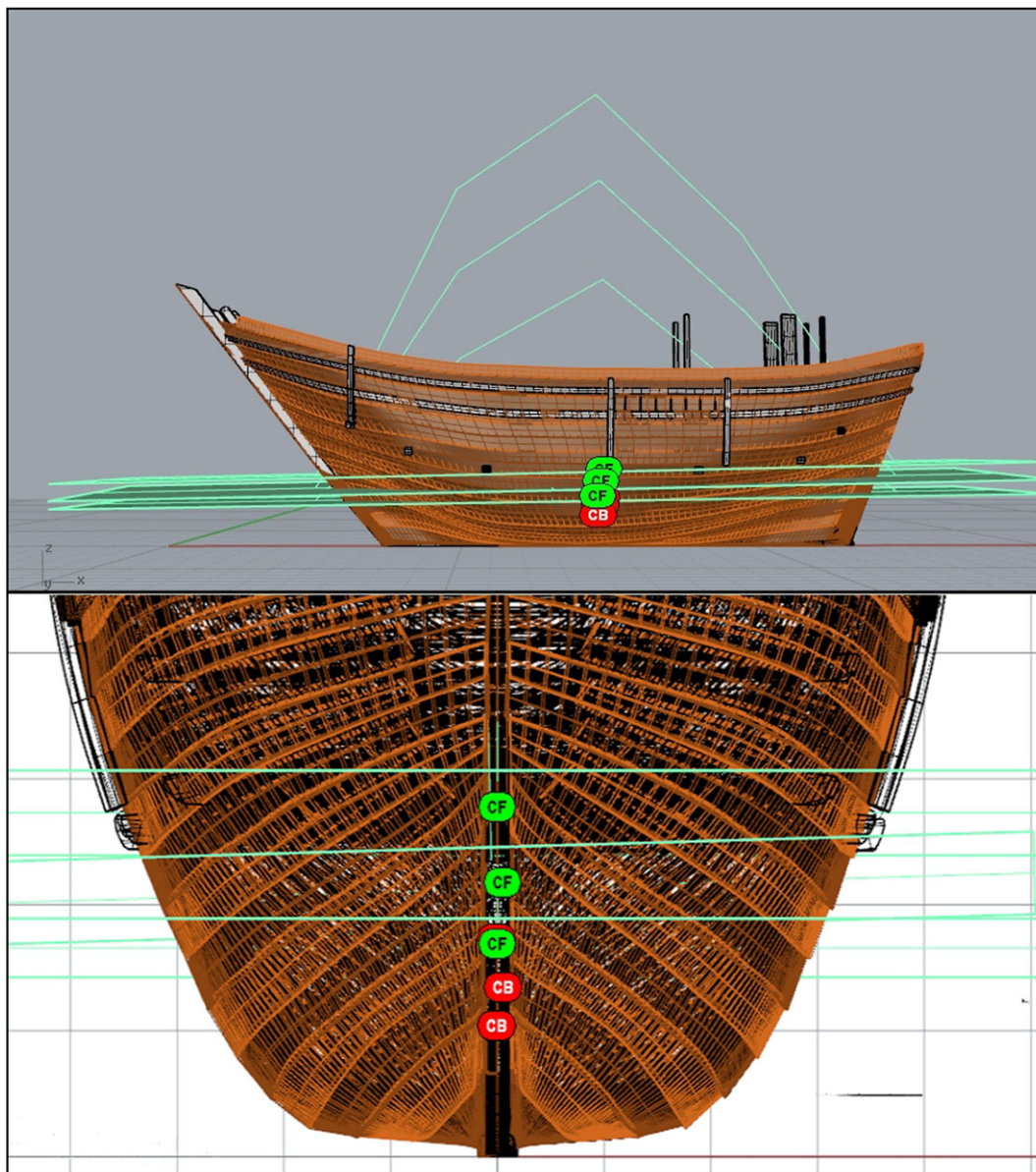


Figure 21. Centre of buoyancy (CB) and waterline (Centre of Flotation, CF) for three different ship weights (see Table 2, rows 1, 3 and 6) (ADC).

that the freeboard of the IJsselcog amply exceeds the requirements for a purely cargo vessel.

The IJsselcog compared

So far 36 shipwrecks with cog-like characteristics have been found in north-west Europe and the Baltic (Table 3). Relatively few of these finds offer data for a comparable study of the hull of the IJsselcog. On the one hand, many of the shipwrecks represent ‘proto-cog-types’, smaller inland cog-like vessels, or relatively incomplete finds. For some, published data is not yet available. At present, the seagoing medieval cog type is

best represented by the OZ36 (Vlierman, forthcoming) and the Bremen cog (Lahn, 1992; Tanner, 2017).

The virtual model was tested focusing on its stability in relation to hull dimensions and cargo volume. Gross cargo volume increases with ship size, as expected (Table 4). However, Table 4 also indicates that the IJsselcog has a lower length to depth ratio than the Bremen cog. The length to width ratio is about the same. Also, it is surprising to find that the net cargo volume is about the same as the Bremen cog for the four sailing conditions on which the calculations are based. It may be that more cargo volume was not the primary driver for the shipbuilder. Was the moulded depth increased for other functional reasons, or was there

Table 3. Overview of cog-like shipwrecks based on Van de Moortel, 2011, Blok, 2014, and Dhoop, 2016 and supplemented with recent data of cog-like cargo shipwrecks from Tallinn and Stockholm

Site	Findspot	Country	Date	Dating Method	Length Overall (m)	Beam (m)	References
1	Kollerup Jutland (N)	Denmark	c.1150	Dendrochronology	20.9	4.92	Crumlin-Pedersen, 1979; Bill, 2002b; Hocker and Daly, 2006; Daly, 2009; tab. 1; Crumlin-Pedersen 2010; tab. 4.1
2	Kolding Jutland (E)	Denmark	1188–1189 (winter)	Dendrochronology	19–25	7.27	Crumlin-Pedersen, 1979; tab. 4.1; Hocker and Daly, 2006; Daly, 2009; tab. 1; Crumlin-Pedersen, 2010
3	Skagen Jutland (N)	Denmark	c.1195	Dendrochronology	17.5	4	Crumlin-Pedersen, 1979; Hocker and Daly, 2006; Daly, 2009; tab. 1; Crumlin-Pedersen, 2010; tab. 4.1
4	Kronsholmen Gotland	Sweden	First half 13th century	14C	–	–	Adams and Rönnby, 2002; 177
5	Kuggmaren I Stockholm Archipelago	Sweden	1215 (summer)	Dendrochronology	–	–	Adams and Rönnby, 2002; Hocker and Daly, 2006; Daly, 2009; tab. 1
6	Oskarshamn Bossholmen, East Skåne	Sweden	after c.1242/1270	Dendrochronology	15	3.55	Adams, 1990; Cederlund, 1990; Daly, 2009; tab.1
7	NA 57 Rutten, Flevoland	The Netherlands	1263–1275	Dendrochronology	–	–	Oosting, 1987; Bill, 2002b; 96; Daly, 2009; tab. 1; Van Holk, 2009; Arbin and Daly, 2012; 383
8	OZ 43 Zeewolde, Flevoland	The Netherlands	1275–1300	Typology of sintels	20	7.32	Daly, 2009; tab. 1; Van Holk, 2009; Gijssbers <i>et al.</i> , 2010; Crumlin-Pedersen, 2010; tab. 4.1
9	Marina Rostock- Warnemünde	Germany	1280	Dendrochronology	>20	–	Förster, 2009
10	OM 61 Dronten, Flevoland	The Netherlands	after c.1296	Dendrochronology	–	–	Daly, 2009; tab. 1; Vlierman, forthcoming
11	Tivoli Kadriori park, Tallinn	Estonia	1296 (tpq)	Dendrochronology	–	6.64	Roio, M. <i>et al.</i> , 2015
12	Darsser Baltic	Germany	1298–1303	Dendrochronology	21	7	Daly, 2009; tab. 1; Förster, 2003; Förster, 2009
13	Pärnu Harbour	Estonia	c.1300	Dendrochronology	–	–	Mäss, 1992, 2000: 56
14	NQ 75 Ens, Flevoland	The Netherlands	1300–1325	Stratigraphy	–	–	Daly, 2009; tab. 1; Van Holk, 2009
15	Rostock-Hohe Düne	Germany	after 1304	Dendrochronology	–	–	Belasus, 2009: 76–78
16	OG 77 Swifterbant, Flevoland	The Netherlands	c.1305	Dendrochronology	>12	>2.6	Daly, 2009; tab. 1; Van Holk, 2009
17	NT 25 Kraggenburg, Flevoland	The Netherlands	1307–1315	Dendrochronology	–	–	Blok and van den Hoek, 2017

(Continued)

Table 3. Continued

Site	Findspot	Country	Date	Dating Method	Length Overall (m)	Beam (m)	References
18 ZC 46	Almere-Buiten Flevoland	The Netherlands	1321–1333	Dendrochronology	–	–	Daly, 2009: tab. 1; Van Holk, 2009
19 Doel 1	River Scheldt	Belgium	1325–1326	Dendrochronology	21	–	Daly, 2009: tab. 1; Vlierman, 2006; Vermeersch and Haneca, 2015
20 Helgeandsholmen II	Stockholm (?)	Sweden	1325/1330	Dendrochronology	–	–	Daly, 2009: tab. 1
21 Doel 2	River Scheldt	Belgium	1325–1335	Dendrochronology	–	–	Vlierman, forthcoming
22 ON 5	Dronen, Flevoland	The Netherlands	1325–1350	Finds	14.5	4.5	Reinders, 1980; Reinders, 1985; Daly, 2009: tab. 1; Van Holk, 2009
23 ZO 36	Zeewolde, Flevoland	The Netherlands	1336	Dendrochronology	20.15 (Rec.)	7.32 (Rec.)	Daly, 2007, 126–127; Daly, 2009: tab. 1; Crumlin-Pedersen, 2010: tab. 4.1
24 NM 107	Emmeloord, Flevoland	The Netherlands	1339	Dendrochronology	15.7	4.5	Reinders, 1979; Modderman, 1945; Van Holk, 2006; Daly, 2009: tab. 1; Van Holk, 2009; Crumlin-Pedersen, 2010: tab. 1; Blok, 2014
25 ZN 42-II	Zeewolde, Flevoland	The Netherlands	1350–1400	Finds	14–15	3	Reinders, 1985; Daly, 2009: tab. 1; Van Holk, 2009
26 Mysingen	Stockholm Archipelago	Sweden	c.1350–1400	Ship technology	>20	8	
27 Lille Kregme	Roskilde Fjord	Denmark	c.1358	Dendrochronology	19.3	6.5	Daly, 2009: tab. 1; Förster, 2009: 320; Crumlin-Pedersen, 2010: tab. 4.1
28 Mollösund 30 (AKA Möllo)	Orust, Bohuslän	Sweden	c.1365	Dendrochronology	–	–	Adams and Rönnby, 2002: 177; Arbin and Daly, 2012
29 Vejby	N. coast Sealand	Denmark	1370–1371	Dendrochronology	17	6	Crumlin-Pedersen, 1979; Daly, 2009: tab. 1; Förster, 2009: 319; Crumlin-Pedersen, 2010: tab. 4.1
30 Bremen	River Weser	Germany	1378	Dendrochronology	22.88	7.68	Lahn, 1992; Daly, 2009: tab. 1; Tanner, 2017, Tanner, 2018
31 Skanör	South Skåne	Sweden	1388–1390	Dendrochronology	20	–	Hörberg, 1995; Crumlin-Pedersen, 2000: 237; Daly, 2009: tab. 1
32 ZN 43	Zeewolde, Flevoland	The Netherlands	1402–1413	Dendrochronology	–	4.3	Van de Moortel, 1991; Daly, 2009: tab. 1
33 Almere Wijk 13	Almere-Stad, Flevoland	The Netherlands	1410	Finds	15.95	4.2	Hocker and Vlierman, 1996; Daly, 2009: tab. 1
34 NM 133-II	Luttelgeest, Flevoland	The Netherlands	?	-	15 (Rec.)	4.5 (Rec.)	Van Holk, 2008, 139; Van Holk, 2013
35 IJsselkogge	River IJssel Overijssel	The Netherlands	1415–1420	Dendrochronology	26 (Rec.)	8.47	Waldus, 2018
36 Wismarbuht 6	Wisnar-Wendorf	Germany	1450–1476	Dendrochronology	18 (Rec.)	6	Förster, 2009: 305

Table 4. *The relation between hull characteristics and net cargo volume of three seagoing medieval cog-type ships for which reconstruction data is available. The moulded depth is measured from the top of the keelplank to the sheerstrake*

	Strakes	Keel length incl. hooks (m)	Beam (m)	Moulded depth	Length overall	Displacement without ballast (tons)	Ballast (tons)	Gross cargo volume (m ³)	Net cargo volume (m ³)	Ratio 1 (Length overall/Max Beam)	Ratio 2 (Length over all/moulded depth)
OZ36	15	12.3	7.32	3.9	20	45.00	25.00	142	117	2.73	5.13
Bremen	13	15.6	7.68	4.3	22.88	58.70	15.00	150	135	2.98	5.32
IJsselcog	18	16.05	8.47	5.5	26	78.40	40.00	177	137	3.07	4.73

an inherent technological limit to maximizing cargo volume when applying the traditional cog shipbuilding methods? The shipbuilder had to be confident that the ship would be stable enough in adverse conditions. This article does not propose answers to these questions. Archival research, however, helps to suggest functional reasons that could have determined the ship dimensions.

A first explanation for the huge size of the IJsselcog might be economic, one of growing demand for cargo capacity. There certainly was a period of sustained economic growth after 1400 of the towns of Holland and Zeeland in the Netherlands (Weststrate, 2008: 35, 37). The 15th-century revival of trade in bulk goods, such as salt, timber, and especially grain, started in the late 12th and early 13th century (Unger, 1994: 288). To protect shipping, merchants travelling in convoy was common practice, even in the Early Middle Ages (Unger, 1994: 289). In northern Europe the economy grew in size, and regional specialization took place in the Middle Ages. This had an impact on maritime commerce, and therefore on the intensity of shipping (Bill, 2002a: 47). In the Netherlands, economic affairs were mainly organized through the towns themselves, with shipping providing the means to organize this growing international bulk trade. Ships, however, served not only an economic role, but were also politically employed to maintain power and to safeguard trade routes overseas.

When the dimensions of the IJsselcog and some of the ship's construction details are compared to other cog-like cargo vessels, the question arises: what was the purpose of these additional constructional elements? The presence of riders on the inboard and additional vertical reinforcements on the outboard, are an indication of the specific and initial purpose for which the IJsselcog has been built. Shipwrecks with similar reinforcements are of the Nordic clinker-built shipbuilding tradition. One example is the ship excavated in Flevoland (the Netherlands) at lot OE34 (Reinders and Oosting, 1989: 106–122; Van Holk, 2003: 296–305; Overmeer, 2017: 199–206). The felling dates of the samples from the timbers of this wreck lie between AD 1522 and 1537; from the artefacts related to the ship's inventory it could be deduced that the ship wrecked between AD 1525 and 1550. The hull of this very large vessel, with a length overall of 33–35m and a maximum beam of 8.5m, was reinforced on the inboard with six pairs of vertical riders (Figs 22 and 23). Since relatively few elements of the inventory were recovered, it was difficult to assess the function of the vessel at first. Thorough investigation by Overmeer showed that a number of items identified on the wreck indicated that the vessel was armed (Overmeer, 2017: 203). Different sorts of shot were present: apron, iron, and stone shot. Tampions for cannon, pike heads, gun-port lids, hinges, parts of a breech chamber, a shot mould, casting ladle, lead ingot, and a part shot gauge; in total 55 items related to armament were recovered. Gun ports were



Figure 22. The OU34 (Dutch State Service for Cultural Heritage, RCE).

also present in the hull. The conclusion that this big ship had a military function seems justified for at least part of its working life (Overmeer, 2017: 205).

The size of another clinker-built ship, the so called 'Big Ship' excavated in Bergen (Norway), might lead to a similar explanation. Jan Bill (2002a: 52) suggests it had been built or used for military purposes in a period when speed was sacrificed for the advantages of height and carrying more men on board. Why do vessels outfitted for battles at sea need to be big? Big in this context means two things: high sides (large depth of hold) and a large carrying capacity. To answer this question, we have to turn to the way medieval sea battles were fought. Pictorial evidence suggests sea battles were similar to land warfare but undertaken from floating platforms (Runyan, 1994: 52). Ships might on occasion ram each other, but the main tactic was boarding and hand-to-hand fighting on the decks and fighting from the higher platforms and top castles. These castles, fore and aft, are often depicted on towns seals. Initially these structures were probably of a temporary nature; after battle they could be taken down (Bill, 2002a: 50). Before the introduction of gunpowder and guns, it was practically impossible to sink the enemy's ship. It might also have been undesirable to do so because a conquered ship was more useful than a sunken one (Bill, 2002a: 49). From a short distance, arrows, darts, or

other missiles were launched but, in the end, boarding was the usual way to settle a battle, in close combat. Preferably, missiles were fired from a position where enemies could be bombarded from above. Justly, Bill used the title 'Castles at sea' for his article on warships in the High Middle Ages. Another implication of the tactics of sea battles in the Middle Ages was that, without the firing power of cannon to destroy the enemy ships, the only way was to outnumber the opponent. This explains why ships for military use were built larger than ordinary merchant vessels. In conclusion, to be successful in battle at sea you needed to have ships that were sturdy (in case of ramming), high (to fire on the enemy from above), and capacious (to host as many soldiers as possible).

This being the case, some aspects of maritime warfare during the Hanseatic period should be considered. At the beginning of the 15th century, the attention of the Hanseatic towns was predominantly focused on combatting privateers (Weststrate, 2005: 36). In March 1394, the leaders of some Hanseatic towns met in Lübeck and decided to equip a fleet of warships. From the distribution of the soldiers in the number of ships, it appears that each cog was to deliver a military force of 100 soldiers (Weststrate, 2005: 36, fig. 7.1). This is a relatively substantial number of people to accommodate on a medieval ship.

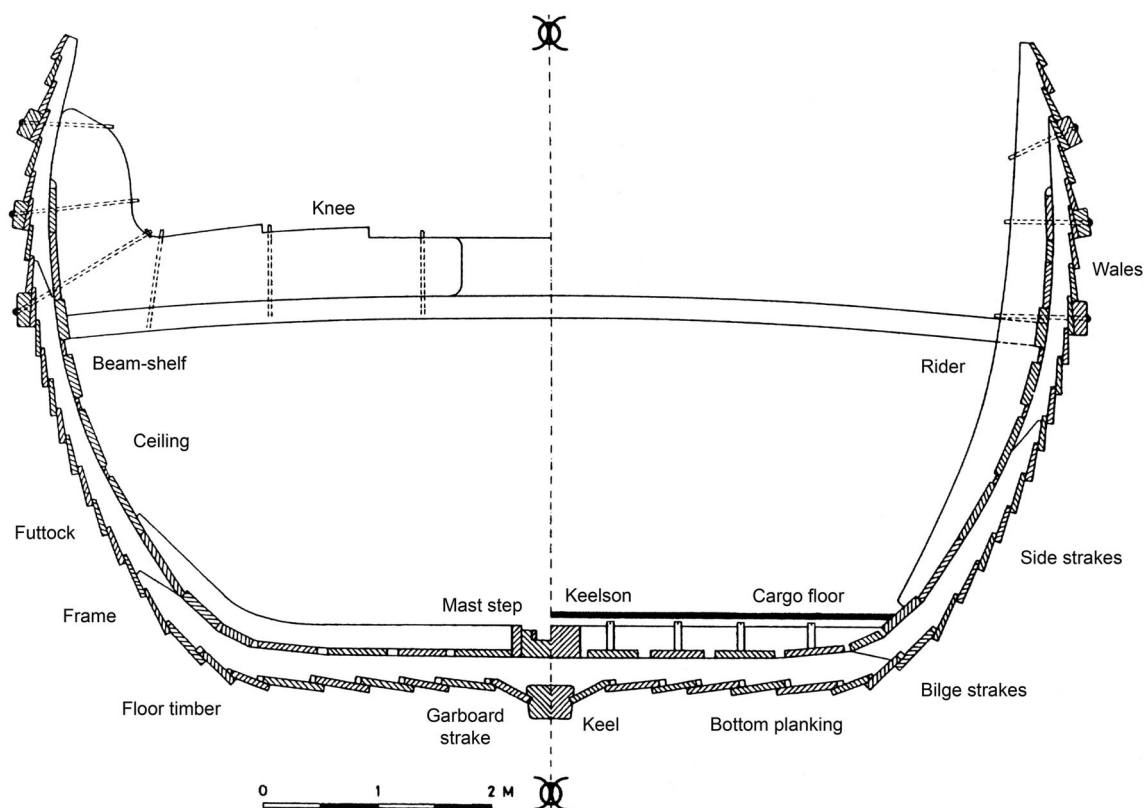


Figure 23. Reconstructed section amidships of the he OU34 (Dutch State Service for Cultural Heritage, RCE).

Including their weaponry—at that time heavy armour, swords, and spears—each person would have a weight of approximately 100kg, making a total weight of approximately 10 tons. On top of this, an unknown percentage of cargo space for eating and drinking gear and victuals has to be calculated. On longer trips, to the Baltic for example, the soldiers had to be fed and needed a place to sleep. The size of a ship necessary to carry this number of soldiers is not clear. It is clear, however, that space was certainly an issue: the bigger the ship the more soldiers it could carry.

During the second decade of the 15th century a conflict arose between the Dutch and Wendish cities (Hamburg, Lübeck, Lüneburg, Rostock, Wismar and Stralsund) that culminated in a true pirate war in the years 1438–1441, known as the Wendish War (Van der Zee, 2018). From 1426 onwards there had been troubles on the North Sea as a result of the growing animosity between the Dutch and Wendish towns. Although each time disputes over confiscated vessels was handled diplomatically (Van der Zee, 2018: 150), there is a good chance that an early variant of convoying existed with purpose-built or at least purpose-equipped ships. It is conceivable that the IJsselcog can be seen in this light.

Sailing Hanseatic waters in the 14th and 15th century was a tricky business. The slow sailing cogs were easy and rich prey for pirates and rival towns,

kings, and countries. Wubs-Mrozewicz (2007: 89, 100) speaks of large-scale conflicts that broke out several times between 1440 and 1560. The Hanse and Lübeck waged war with Flanders, France, England, Denmark, Norway, Sweden, and Holland in the late Middle Ages. ‘Hollanders’ intercepted *Bergenfahrer* ships, while Burkhardt (2007) has given a detailed account of the havoc wreaked by both German and English pirates in the North Sea from the early 15th century until at least 1468.

How did the Hanseatic towns tackle this problem? A successful solution was to sail in convoys. Ships would assemble at a certain spot to form a fleet that could defend itself more easily against pirates. An example of this strategy is the salt trade, where skippers would wait in Dutch-Flemish waters, usually in the *Zwin*, until a robust fleet had formed, to sail together—in convoy—before the start of winter to the south through the Channel to load salt at Bourgneuf (de Boer, 2005: 46–47; Jahnke, 2009: 58).

Relevant to the interpretation of the IJsselcog as a military vessel, is the composition of the convoys. Was it only the size of the fleet that provided safety, or were the merchantmen escorted by armed military vessels? The Hanse could call on members to equip *vrede*schepen, military vessels that served as escorts for merchant vessels sailing in convoy (Lensen and Heitling, 1990: 140). In Dutch *vrede* means piece, but in this case the

word *vrede* has another meaning, in old-Dutch the verb *vrede* means to fence off or enclose.

What did a *vrede* fleet look like? In 1394 Lübeck delivered six cogs for a *vrede* fleet, each armed with 100 men, Stralsund four cogs with 400 men, Greifswald two cogs with 120 persons and Szczecin also two cogs with 200 men. The city of Kampen provided two cogs and four ‘Rhineships’ with a crew of 300 men (Lensen and Heitling, 1990: 141).

Another, cheaper solution was to keep an armed fleet at sea, especially in the tidal outlets. The town of Stade, for example, was paid to keep the entrance of the river Elbe free from pirates with a defensive fleet.

In 1395 the Hanse decided at a *Tagesfahrt* (meeting of Hansards), at Lübeck again, to equip *vrede* ships. This was repeated over the following 25 years, for example in 1399, 1400 and 1407. The growing demand for *vrede* ships between 1390 and 1422 was, among other reasons, a response to the actions of the *Vitalienbrüder* pirates (Lensen and Heitling, 1990: 145–148).

In the IJsselcog a large fireplace and a dome oven built of bricks, was found (Fig. 8). Usually the hearth aboard medieval vessels consists of a wooden box filled with sand with a layer of tiles on top (Vlierman, 1997; Vlierman, forthcoming). On top of the tiles an open fire was kindled. A ‘firebox’ of this kind was far too small to prepare food for a group of about 100 soldiers. A similar, relatively large galley arrangement was found on board a merchant *tjalk*-like vessel dated to the 17th century, found at lot OK45 in the province of Flevoland. With its overall length of about 20m, it is a medium-sized vessel that could be sailed by a small crew. The ship was originally built as a merchant vessel and at a later date equipped as a military one. Cannon and other weaponry were found on board, besides a large quantity of cooking utensils and eating and drinking gear (Vlierman, 1997: 157). There were two fireplaces: one in the bow and one just behind the mast. Ships of this size usually have only one fireplace. The fireplace behind the mast was probably built to prepare food for the soldiers on board. The composition and size of the galley of the IJsselcog might point in the same direction.

Several iconographic representations of medieval warships depict soldiers on board (Fig. 24). The ships also show some constructional features on the outboard: in the bow of the vessel in the foreground, vertical reinforcements can be seen, while the upper sides seem to be reinforced by three wales.

The size and especially the height of the IJsselcog might suggest that the ship was designed as a military vessel. This does not mean, however, that the vessel had an exclusively military function. In the hold, extensive constructional features have been found and reconstructed that consist of cargo floors and shifting-boards to separate different kinds of cargo, as described above. But this comes as no surprise as warfare at sea was a part-time occupation. As learned from the organization of the Hanseatic towns, only in times of



Figure 24. Late 15th-century illustration of vessels showing boarding and close combat. Note the wales and vertical reinforcements on the outside of the vessels (from Jean de Wavrin's *Chronique d'Angleterre*, produced at Bruges for the library of King Edward IV, with permission, British Library, Royal Ms 14, E IV, f276r).

trouble were fleets assembled, manned with the town's inhabitants, with each town providing a certain number of cogs and supporting vessels.

Conclusion

In this article recent research about the 15th-century IJsselcog has been discussed in order to explain how the 3D reconstruction of this shipwreck was arrived at, taking into account its archaeological and historical context. As one of the latest of the seagoing cog-like cargo vessels found, the IJsselcog can be characterized as a ‘classic’ cog with all the characteristics that define this shipbuilding tradition. However, some remarkable constructional elements are present. It might be concluded that the builders of the IJsselcog maximized the hull volume and height to combine the functions of cargo vessel and warship. This is mainly expressed in the use of vertical reinforcements and applied wales as a strengthening measure for the relatively high freeboard. These shipbuilding traits that allow higher and more complex hull constructions were generally applied to 16th- and 17th-century carvel-built cargo vessels. The hypothesis that this relatively large cog was constructed for warfare in addition to its primary function as a cargo carrier, may be supported in the context of late medieval society, where conflicts at sea were settled in battle using ‘floating castles’.

The deformed and partly distorted state of the hull of the IJsselcog was critical to the decision to base the reconstruction project on handmade 2D construction drawings. Nevertheless, a point of discussion may still be whether or not a wholly digital approach using exclusively 3D technology would have led to the same results. A wooden scale model reconstruction will be realized in 2019 at the *koggewerf* in Kampen. The authors of this article are convinced that 3D technologies are vital in enhancing the efficiency and accuracy of recording, and should therefore always be used to support the complex and time-consuming process of interpreting wooden shipwrecks. Since most shipwrecks are encountered in an incomplete, and deformed condition, it is important to realize that the success of the interpretation process and subsequent reconstruction projects primarily hinge on the work of the nautical archaeologists. Based on the 3D model of the IJsselcog some first nautical calculations are presented in this article. It is important to stress that

only the static stability of the IJsselcog in coastal waters has been calculated. Many other options are conceivable, such as calculating the dynamic stability in open sea. Other sailing conditions should be considered, such as the transport of heavy cargo, or transport of troops and maritime warfare equipment. Since the actual reconstruction of the IJsselcog leaves some questions unanswered concerning the possibility of a bow castle and rigging, future research is needed to define more completely the nautical characteristics of this cog.

Finally, the software package Orca 3D of Rhinoceros offers unprecedented possibilities to calculate nautical characteristics of reconstructed ships. Having such an innovative tool in hand, nautical archaeologists should collaborate on the development of standardized methods of analysis for reconstructing wooden shipwrecks. This will increase the comparability of 3D research projects and open new fields of research.

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Notes

1. Archaeological company with a maritime archaeology department based in Amersfoort: www.archeologie.nl.
2. Civil dive company specialized in measurements underwater and geophysical surveys: www.baars-cipro.nl.
3. Maritime company specialized in heavy lifting and salvage, based in Zwartsluis and Rotterdam: www.hebo-maritiemservice.nl.

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