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ORIGINAL ARTICLE

Sheathing and Pay Techniques in the Boa Vista 1 Ship (Lisbon, Portugal)

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Abstract
Between September 2012 and February 2013, archaeological excavations carried out in the riverside area of Lisbon (Portugal) revealed the remains of two wooden ships: Boa Vista 1 (BV1) and Boa Vista 2 (BV2), both dating from the late seventeenth or early eighteenth century. BV1 ship consists of scattered hull timbers which were damaged and out of their original positions. Some of the ship's hull features are common in the Mediterranean like a composite keel with butt joints and hook scarfs in the connection between floors and futtocks, while others are well-known Iberian shipbuilding features like the transition between the keel and the sternpost being made through a single piece, the heel. A unique feature was a layer of animal hair between the sheathing and the hull planking. This paper focuses mainly on the study of wooden sheathing, including but not limited to the analysis of its conventional "architectural signatures". The latest results concerning animal hair identification will also be presented and discussed, showing the added value of multidisciplinary approaches in archaeology.

Keywords Nautical archaeology · Urban archaeology · Early modern archaeology · Sheathing · Animal hair

1 Introduction

The Archaeological Context

The archaeological works conducted in the scope of the construction of EDP's (Energias de Portugal S.A.) new corporate headquarters, south-east from the intersection of Rua D.

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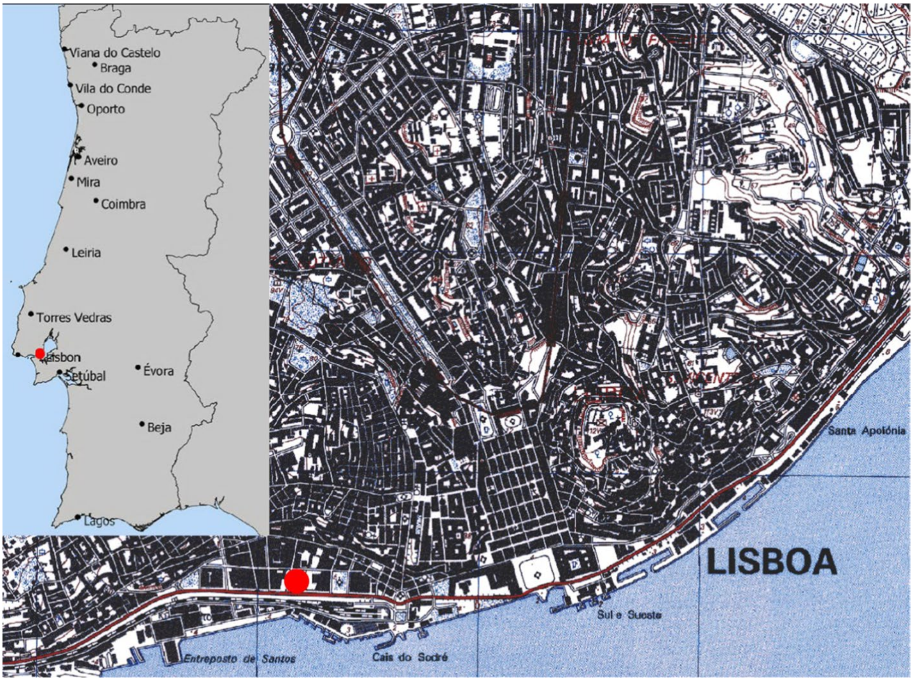

Fig. 1 BV1 site location in red circle (Carta Militar de Portugal, scale 1:25 000, excerpt of sheet 431)

Luís I and Boqueirão dos Ferreiros (Fig. 1), unveiled the remains of two ships, Boa Vista 1 (BV1) and Boa Vista 2 (BV2). The archaeological investigation was carried out between September 2012 and February 2013 by ERA Arqueologia S.A. Company, which requested the collaboration of CHAM–Centre for the Humanities NOVA FCSH-UAc) in providing the required nautical archaeology expertise (Bettencourt et al. 2021, p. 101).

The ship remains were located on the riverside area of Lisbon, at the former Boa Vista beach, a submerged area until the eighteenth century. From the mid-seventeenth century onwards, this area became an anchorage with some wharfs and warehouses, mostly belonging to the Junta do Comércio do Brasil (Araújo 1993, p. 75).

The site's stratigraphic sequence included three different phases: the earliest one consisted of various remains related to the former Boa Vista beach, particularly the two aforementioned ships, as well as some elements related to port activities; the second phase corresponded to the Boa Vista landfill, with a considerable thickness, started after the 1850 decade (Araújo 1993, p. 85) and over which the Fábrica de Gás da Boa Vista (gas works; the third phase) was built. The gas works operated between 1847 and 1914, when a major explosion triggered its relocation to the Bom Sucesso area (Araújo 1993, p. 77). The remains, predating the Boa Vista landfill, were packed in four sedimentary units deposited in a subtidal, low-energy environment. The sediments clearly show an increase in anthropic materials, particularly some Roman amphorae but mostly ceramics, heavily crushed glass, and some anchors dating to the sixteenth, seventeenth and eighteenth centuries (Costa et al. 2016, pp. 93–94).

The BV1 ship was found precisely in these sediments, on a subtidal area just 49 centimetres (cm) below the lowest tide, which means its remains have been easily accessible during ebb tides since its abandonment. A small amount of materials directly related to the

Fig. 2 Archaeological materials found above BV1 ship and therefore a *terminus ante quem* for the ship's chronology. (Adapted from Bettencourt et al. 2013, pp. 18–20)

ship were recovered during the excavation and include three pulley blocks and some associated cordage. The hull was sealed by deposits containing various materials, such as English onion bottles, Rhenish stoneware pots, Dutch and English kaolin pipes, and Portuguese faience (Fig. 2) (Fonseca et al. 2016, p. 962).

These artefacts are, however, unrelated to the BV1 ship, either because of the broad time span they cover and probably resulting from the use of the western riverfront area of Lisbon as a harbour. They are, nevertheless, good chronological indicators as they indicate a time-frame for the ship somewhere between mid-seventeenth and mid-eighteenth centuries (Bettencourt et al. 2013, pp. 17–21).

The BV1 ship was excavated and recorded in situ by means of orthophotography and using a total station. The timbers were dismantled and kept immersed in water tanks until they entered into primary conservation treatment at the Rego facilities of the Centro de Arqueologia de Lisboa (CAL). The field data thus gathered have been analysed and processed, including a general inventory of all the recovered timbers and archaeological artefacts (Bettencourt et al. 2013).

The Hull of The Boa Vista 1 Ship

The *Boa Vista 1* ship was preserved over a length of twelve metres, from north to south, and a width of five metres (m), from east to west. The preserved section includes the ship's stern, from the keel to the tenth strake of the planking on the starboard side and to the second strake on the port side (Fig. 3). The stern was located at the southern end, resting on the starboard side and including a terminal section of the keel, the heel, and the sternpost. A central section of the vessel, cut during previous phases of occupation in this space, was found at the northern end. The context was globally disturbed due to the placement of landfill piles dating to the eighteen hundreds and contaminated by naphtha, used as fuel at the Fábrica do Gás da Boa Vista. A total of 703 hull timbers belonging to the BV1 ship were recovered during the archaeological excavation. No frames were found crossing the keel;

Fig. 3 Overall view of BV1 ship during the first stage of the archaeological intervention (photograph: CHAM archive)

the south-east portion of the scatter of timbers featured a chaotic assemblage of wooden elements, apparently collapsed from the starboard topsides. Thus, the only hull parts found in situ were a section of the keel, the hull planking, the sheathing, and some starboard futtocks, knees and stringers, and some fragments of Y-frames close to the heel (Bettencourt et al. 2021, pp. 101–102).

The Keel and Heel

The keel consisted of three sections, measuring a total of 11.72 m, and was preserved as far as the stern. It has a rectangular section, with a width between 15 and 16 cm and a height between 19 and 22 cm. The three sections (EDP_0023, EDP_0089/0502, and EDP_0342/0343) were connected by butt joints, without any signs of a fastening system but displaying all along their width and below the rabbet a number of semicircular horizontal notches 2 cm in diameter to fit pegs, which would function as a stop water. The transition from keel to sternpost was made through a 3.47-m heel. Both sides of the heel had rabbets continuing up from the keel to fit the garboards (Bettencourt et al. 2021, pp. 102–103).

The Framing

The ship's framing was mostly ex situ and only one floor timber and only 15 futtocks, corresponding to 30 fragments, remain in their original positions along the starboard side. At the southern end, seven Y-frames were close to their original position on the *heel*. All preserved timbers were recovered and some are well preserved.

A total of five floors, 55 futtocks, and 136 frame parts were recorded. The fastenings and the frame negatives on the inner side of the planking and the keel indicate that the frames had between nine and 14 cm sided, in the centre of the vessel. The space between frames ranged from 14 to 24 cm, corresponding to a room-and-space distance of ca. 30 cm. The futtocks were quadrangular in section, and measure between 7.5 and 13 cm sided and 8 and 11.5 cm moulded. The fastenings on the upper side of the keel indicate that each frame was fastened by at least one square iron nail, 1 cm in cross-section. At intervals of three to four frames, there were iron pegs measuring 1.8 to 2.2 cm in diameter, with round heads embedded in pre-drilled countersunk holes, probably corresponding to the keelson-frame-keel connection (Bettencourt et al. 2021 p. 104).

Two hook scarves were recovered among the framing fragments from the centre of the vessel and were nearly in its original position, in the connection between floor timbers and futtocks; this was the only part of the structure where these connections were preserved. However, other hook scarves were found amid the scattered fragments of the framing. The futtocks were apparently located towards the extremities of the ship. The scarves measured 1.1 to 1.6 cm in depth. The joints were probably reinforced with two or three iron nails, with round heads embedded in pre-drilled countersunk fastening holes measuring 2.5 to 3.3 cm in diameter. The floors and futtocks that made up the Y-frames were fastened to each other with nails driven obliquely from their moulded faces. The nails measure 1.5 cm in cross-section and had round heads measuring 3 to 3.5 cm in diameter that were countersunk in the timbers in pre-drilled fastening holes. In some cases, it was possible to observe the placement, from the upper side, of one or two square pegs, 2 cm to a side, also with round heads embedded in previously drilled countersinks 3 to 3.2 cm in diameter. The Y-frames were also attached to the futtocks with square, 1-cm iron nails.

Stringers, Footwales, and Knees

Only two out of the 22 stringer fragments were found in situ, but the presence of iron fastening holes on the moulded faces of the futtocks indicates the use of more elements. None of these pieces kept their original length, but the largest measured 3.14 m in length, 19 cm in width and the outboard face was indented to fit the frames; its thickness ranged from 6 to 7.5 cm. It was attached to the frames by two 1-cm-wide iron nails per joint, with round heads embedded in pre-drilled countersunk holes measuring 2.5 cm in diameter. There were eight footwall fragments, the largest of which was 1.78 m in length and it was displaced; it measured 19.5 cm in width and 10 cm in thickness and featured a plain scarf. We also identified five hanging or lodging knees, with iron fastenings very similar, in shape and dimensions, to the ones used in the framing (Bettencourt et al. 2021, p. 104).

The Hull Planking

The hull planking was in good condition, especially on the starboard side, on the northern part of the structure, where 10 strakes of planking were preserved. On the port side, only two strakes were preserved. In total, 253 elements were identified, including some repair planks. Only one plank was complete and measured 4.61 m in length. The width of the hull planks measured between 5 and 40.5 cm, the majority ranging between 22 and 28 cm, and the thickness between 4 and 5 cm, the majority ranging between 4.7 and 5 cm. The narrowest widths may correspond to repair planks, placed at a later stage of the ship's life, but can also correspond to original timbers put to replace aberrations of the natural growth of the timbers, like knots.

The planks were joined with butt joints whereas plain scarves can be observed on some patches. The hull planking was attached to the frames with square nails, measuring 0.9 to 1.3 cm in section, with round heads embedded in pre-drilled countersunk holes with 2.4 to 3.3 cm in diameter buy mostly between 2.5 and 3 cm. The pattern of these joints varied between two and four nails along the plank, sometimes up to six on the ends. Small square wooden wedges, 1 cm to a side, were occasionally observed and were probably used provisionally while the wooden sheathing was being attached, since they are driven through. Some planks also feature square holes, measuring 0.8 to 1 cm in width, which probably represent fasteners that connected the sheathing and hull planking to the frames since there are no traces of the heads and the nails were driven through the entire thickness of the fastened parts (Bettencourt et al. 2021, p. 104).

The Sheathing

The exterior of the hull, including the keel and heel, was protected with a layer of wooden sheathing, consisting of 146 sheathing planks (Fig. 4). The length of the complete planks varies between 1.66 and 4.19 m, with widths between 20 and 28 cm and thicknesses between 2 and 3.5 cm. The sheathing was fastened mainly along the edges of the planks with small iron nails, with shafts squares in section measuring 0.5 to 0.7 cm in section and with the round heads measuring 1 to 1.3 cm in diameter. The nail heads were countersunk in the planks via pre-drilled fastening holes 2 to 3 cm in diameter. The nails were driven through the planks and probably correspond to the sheathing–hull planking–framing connection. As previously mentioned, small square wooden wedges, 1 cm in cross-section, were observed, which must have been provisionally used when the sheathing was being fitted, since they were driven from the outer face of the sheathing, crossing its entire thickness and ending in the middle of the hull planking (Bettencourt et al. 2021, pp. 104–105).

A layer of animal hair, 0.5 to 0.8 cm in thickness, was placed between the hull planking and sheathing planks, as well as between the keel/heel and sheathing. In some cases, there were circular holes 2.5 to 3.2 cm in diameter, crossing the whole thickness of the planks but not leaving any negative marks on the hull planking. Animal hair mixed with mud and naphtha, which covered the whole context, was also observed inside the holes. These orifices probably existed in all the sheathing elements, since the complete planks have two, and in some cases three such holes, while in the incomplete planks there is only one, or even just traces of one in the most fragmented planks, hence the conjecture. These holes were always placed in the same area, between 30 and 50 cm from the planks' ends.

In the seventeenth and eighteenth centuries, the use of a sacrificial sheathing and the presence of animal hair between the hull planking and the sheathing were mainly used by Northern Europeans, such as the Dutch, French, British, Swedish, and Danish, shipwrights in the construction of ships that sailed to the Mediterranean and to tropical waters (Martin 1978, pp. 49–50). In Portugal, historic references for the use of sheathing exist from the seventeenth century onwards, but the first example from the archaeological record comes from the BV1 ship (Bettencourt et al. 2017).

Seven sheathing planks have incised markings (Fig. 5) of unknown meaning, but which could be the mark of the owner or of the naval carpenter who carried out the felling of the trees. The mark is always the same and is placed on the inside of one of the planks.

Sheathing Planks

The purpose of wooden hull sheathing is to protect the hull and exterior surface of the ship below the waterline. Sheathings can be made of wood or different types of metal (lead, copper, or brass). The purpose of this kind of material is to protect the vessels from marine organisms and xylophagous worms. At the same time, they may function as a space

Fig. 4 The BV1 ship sheathing planks during the archaeological works (Photogrammetry: CHAM archives)

filler between the planks and different layers of hull planking, but always have in mind the watertightness of the vessel (Ryder 1998b, p. 55).

The use of a sacrificial sheathing is primarily needed to protect the wooden hulls from xylophagous worms, the best known of which is *Teredo navalis*. Also known as shipworm, this is a xylophagous bivalve mollusc that feeds on submerged wood. As it burrows, its

Fig. 5 Incised marking on inner face EDP_0247 sheathing plank (photographs by the authors)

Fig. 6 Present-day distribution of *Teredo navalis*. Available at https://www.cabi.org/isc/datasheet/97284819#toDistributionMaps, accessed 06/09/2020

glands spew out a whitish substance, composed mostly of calcium carbonate, which eventually consolidates its own tunnels (Marr 2012, p. 9).

It is unknown when this mollusc was first observed on wooden ships. There are many theories about its origin; some argue that it was introduced in the waters of Northern Europe from the Indo-Pacific region, from the West Pacific region, the East Indies, or from the Mediterranean, while others still maintain that it first appeared in the North Sea area. In other words, its origin is actually cryptogenic (https://www.cabi.org/isc/datasheet/97284819).

The theory that has gained greater consensus is that the species initially existed only in the Atlantic Ocean, in the temperate waters between the USA, Brazil, and the West African coast, and in some areas of the Mediterranean (Staniforth 1985, p. 21). The expansion of global seafaring increased navigation in tropical waters, which resulted in the dissemination of this mollusc, which was transported in the hulls of ships and eventually adapted to the new territories (Brinkbaumer et al. 2006). Nowadays, it has a very wide distribution (Fig. 6), being more frequent in temperate and low salinity waters (Staniforth 1985, p. 21).

Even though it is a tiny creature when it enters ship timber, *Teredo Navalis* worms can grow up to 3 cm in diameter and 60 cm in length (Hoppe 2002, p. 116). The oldest historical sources, where damage caused by *Teredo navalis* is mentioned, date back to Theophrastus (371–328 B.C.) and Ovid (43 B.C.–A.D. 17) (Steinmayer and Turfa 1996). Another threat to wooden ship hulls was *Limnoria* sp., a small isopod crustacean that also feeds on submerged wood. These invertebrates cannot survive in dry environments and their presence is extremely limited in very cold waters.

The use of sheathings arguably started in the sixteenth century, shortly after the first return voyages from the warmer waters of the Indian Ocean (Van Duivenvoorde 2012a, p. 242), and became widespread in the seventeenth and eighteenth centuries. There was a strong contribution from the *Verenigde Oostindische Compagnie* (VOC; founded in 1602) ships, which used a layer of sacrificial sheathing, mostly comprised of pine planks (Van Duivenvoorde 2012a, p. 241). It is important to note that this layer required constant maintenance, with some elements having to be removed and replaced every two to four years (Van Duivenvoorde 2012a, p. 242). This may possibly be the reason why several patches were identified on the BV1 ship sheathing.

The use of wooden sheathing may also reflect the need to extend the ship's life span (Marr 2012, p. 13), and this may be the case with BV1 ship, since some of the hull planks were already badly deteriorated, either due to the ship's use or to the action of *Teredo navalis*. Another fact that could supports this hypothesis is that several patches were identified on the hull planking, which could indicate the vessel was not in the best condition or had several voyages on its hull. Nevertheless, it is just a hypothesis and these narrow planks can either correspond to repair planks placed at a later stage of the ship's life, or to original timbers put to replace aberrations of the natural growth of the timbers, like knots.

Hull Caulking, Paying, and Protection Techniques

Since the beginning of seafaring, humankind has used a wide range of techniques and solutions to protect vessels. Developed over millennia, wood, lead, zinc, copper, clay, papyrus, moss, plant fibres, and animal hair have been used (Cappers et al. 2000, p. 577; Marr 2012, p. 9). Vessels evolved, but the need for protection remained. The act of caulking and paying a vessel was performed not only at the time of construction, but also during repairs (Cappers et al. 2000, p. 577).

Good caulking materials must have several characteristics, such as watertightness, malleability in order to be inserted between the plank joints, durability, i.e. the ability to withstand changes in temperature and salinity, and immunity to microbiological deterioration. The most important criteria, however, are the availability of resources in time and space, since caulking a medium-sized ship requires a large amount of material (Cappers et al. 2000, pp. 577–578).

The use of caulking materials has a long and ancient tradition in shipbuilding, in all parts of the world. The Carthaginians and Phoenicians were among the first to use chemical agents in their vessels, such as mixtures of wax, tar, pitch, or clay. Some of these techniques are more related to waterproofing while others are intended to make the hull smoother, thereby improving the ship's performance (Marr 2012, p. 12). According to Strabo, the Gaulish Veneti tribe used seaweed in their vessels. The use of reeds, hammered to form a viscous substance that could last for a long time, is also documented in Gaul.

The dhows used mainly for trading in the Indian Ocean from the Middle Ages onwards were caulked with cotton or fish oil mixed with tow. Two substances are mentioned in most Arabic sources: a mixture of tow and date palm oil and a combination of resin or pitch with whale or shark oil (Cappers et al. 2000, p. 578).

The application of lead hull sheathing has also been documented archaeologically since at least the fourth century B.C., on the Kyrenia ship (Cyrus) (McCarthy 2005, p. 101), which had 3-mm-thick lead sheets attached to its hull with copper tacks (Katzev 2005, p. 77). In addition, other Greek and Roman shipwrecks with lead sheathing, attached with small copper tacks, include the Lake Hemorese ship (Naples, A.D. first century) or the Lake Nemi ships (Lazio, A.D. first century) (Frost 1973, p. 33; Staniforth 1985, p. 21). Moreover, lead sheathing was also used on some ships of the *Invincible Armada* (1588) and the English Royal Navy, in the seventeenth and eighteenth centuries (Staniforth 1985, pp. 21–22). Despite its use over centuries, its drawback was always the corrosion of the iron tacks, because the contact between iron and lead caused a galvanic reaction, an electrochemical process through which one metal corrodes another when in the presence of a corrosive electrolyte (Staniforth 1985, p. 22).

The VOC coppered the stern posts of its ships in the seventeenth and eighteenth century, and archaeological examples include the shipwrecks of *Nassau* (1606), *Batavia (1629)*, the *Vergulde Draak* (1656), and *Buitenzorg* (1760) (Van Duivenvoorde 2015a, p. 351). Around the same time, the English Royal Navy also started using copper for the sheathing of some of its ships, like the *Alarm* (1761) (Staniforth 1985). With the experience achieved from building hundreds or thousands of ships, shipwrights became aware of the galvanic corrosion caused by iron nails and gradually introduced copper tacks for sheathing.

As previously mentioned, the use of a sacrificial sheathing began around the mid-sixteenth century, but it was in the seventeenth century, in countries such as Sweden, Denmark, the Netherlands, France, and the UK, that it became widely used (Van Duivenvoorde 2012a, p. 242). As a rule, a layer of pitch was applied between the hull planking and the sheathing, to which animal hair was subsequently added. The purpose of this hair layer was to give volume to the pitch, thus reducing wood rotting and preventing xylophagous molluscs from reaching the planking (Van Duivenvoorde 2012a, p. 242; Van Duivenvoorde 2015b, pp. 102–106; 175–176).

Dutch ships commonly used cattle and goat hair, e.g. on *Batavia*, *Mauritius* (1613), *Kampen* (1627) and *Buitenzorg*. Indeed, cattle and goats were the main livestock species in the Netherlands during the seventeenth and eighteenth centuries (Van Duivenvoorde 2012b, p. 13). The type of material used in the caulking of a ship is always related to the environment in which it is built (Ryder 1998a, p. 62). Even though the existing historical documentation attests to this practice (Van Duivenvoorde 2012b, p. 13), the use of the hair of a particular animal is not mentioned (Van Duivenvoorde 2012a, p. 248). Some authors argue that horse and cow hair are best suited for the sheathing of a ship as they are supposed to be indigestible by xylophagous worms and, when mixed with tar or pitch, create an almost impenetrable barrier (Chatterton 1914, pp. 117–118).

Another technique used recurrently and, in some cases, concurrently with animal hair, was the application of organic compounds, such as gala-gala and pitch. These had a double function: on the one hand, they waterproofed and, on the other hand, protected the wood from shipworms. These types of substances have been identified in some shipwrecks, such as RAVF (16th century) (Lopes et al. 2020, p. 17) and Boa Vista 2 (mid-seventeenth to mid-eighteenth century) (Bettencourt et al. 2017, p. 403). In fact, the use of waterproofing materials made of plant fibres, to which tar, pitch, resin, and sometimes beeswax, were added has been known since the second century B.C. (Colombini et al. 2003, p. 663). The

Romans favoured the use of small wood shavings, while in the Middle Ages sheep's wool and goat, cattle and horse hair were widely used, and actually found on the Newport ship (mid-fifteenth century) (Nayling and Jones 2014, p. 262). From the Modern Age onwards, linen and hemp began to be used as well in large quantities. In the case of Lisbon, it is even attested that in 1804 there were 100 women making tow that was used to caulk ships (Oliveira 1804, p. 181).

Mailletage was also used to protect the hull planking of ships. This consisted of placing hundreds of small iron nails in a regular quincunx pattern at about five cm intervals, ensuring a more even build-up of corrosion products to inhibit the invasion of marine borers (Van Duivenvoorde 2012a, p. 247). This technique was sometimes applied on the wooden sheathing itself, thus providing double protection. This type of protection has been observed mainly on VOC ships[1], but also on some British and French vessels (Van Duivenvoorde 2015b, p. 195; Van Duivenvoorde 2012b, p. 7). And also in Portugal, namely in the excavations of Boqueirão do Duro, in Lisbon, where two sheathing planks, 2.5 to 3 cm thick, were recovered, which were reused in the construction of a port structure and featured precisely this technique (Lopes et al. 2021, 357–359).

VOC's ships featured different but very similar solutions for waterproofing and protection. The *Batavia* ship had a pine sheathing with hundreds of filling nails with heads used as *mailletage*. In addition, it was payed with a mixture of sulphur and tar. The *Mauritius* ship (L'Hour et al. 1989, p. 215) and the Monte Cristi ship (Dominican Republic) (Hall, 1996, p. 70) were also payed with a mixture of tar and sulphur (Van Duivenvoorde 2015b, p. 106). The Christianshavn B&W 2 ship yielded crushed glass, in addition to sulphur and tar (Lemée 2006, p. 203). The *El Triunfante* ship (Catalunha 1795) featured a protection composed of a mixture of tar, cow hair, dog hair, and crushed glass (Pujol i Hamelink et al. 2013, p. 151). Several layers of copper interspersed with lead covered the sternpost of *Vergulde Draak*. The Barrel Wreck (Robben Island, South Africa, mid-seventeenth to mid-eighteenth century) had traces of lead sheeting both on the stem and on the heel (Van Duivenvoorde 2012b, pp. 10–12). The sheathing was generally between 2.5 and 5 cm in thickness, depending on its position on the ship's hull and chronology (Van Duivenvoorde 2012b, p. 7).

Another study, based on 182 caulking samples from 98 different ships, indicates that moss was used in the caulking of Dutch ships of the late Middle Ages and also mentions that ships of the Modern Period mixed moss and animal hair in their covering (Cappers et al. 2000, pp. 584–585).

Another problem that has affected and continues to affect vessels is fouling, particularly on the base of the hulls, mainly the growth of algae, barnacles, and other small crustaceans. Apart from being harmful to the ship itself, fouling impairs the vessel's performance, slowing its speed and making it difficult to handle. One of the most popular solutions to solve this problem, between the fifteenth and eighteenth centuries, was careening.

To sum up, the Age of Global Seafaring brought the need for bigger ships, capable of carrying tons of goods and crews all over the world for several months, which led to the development of measures to protect the ships' hulls, thus extending their useful life. These measures evolved and adapted to changing needs. Although the use of plant fibres or animal hair as caulking and waterproofing elements is known, there have been few studies on

[1] *Mauritius*, *Kampen*, *Batavia*, *Vergulde Draak*, *Avondster* (1659), *Kennermerland* (1664), *Zuiddorp* (1712), *Risdam* (1727), *Zeewijk* (1727), *Buitenzorg* and *Nieuw Rhoon* (1776) (Van Duivenvoorde 2012a, p. 242).

Fig. 7 Horse hair found between BV1's sheathing and hull planking (photographs by the authors)

the subject. On the one hand, there are few archaeological sites with this type of evidence, and on the other hand, as they require an interdisciplinary approach that is not always easy to achieve, and not infrequently involves high costs, they are often overlooked. It is in this context that the present study fits and seeks to contribute.

The Boa Vista 1 Animal hair

As previously mentioned, naphtha residues from the gas works contaminated the whole context of BV1 ship, and the sheathing was no exception. In fact, the animal hair layer was completely impregnated with naphtha, so that it is almost impossible to determine whether a resinous paying material or other binder was actually used. Perhaps chemical analyses can delineate the original paying material used in the future.

The sheathing of BV1 ship covered its exterior, including the hull planking, keel and stern heel. This is similar to the sheathing of ships like *Batavia*, Christianshavn B&W 2, *Mauritius* and *Buitenzorg* (Van Duivenvoorde 2012a, p. 247), and also the *Listel 1* ship (southern coast of France, seventeenth century) (Beltrame et al. 2014, p. 48) and the presumable *Croce Rossa*, sunk in 1715 at the Venetian harbour of Malamocco (D'Agostino et al. 2010).

During the individual cleaning and recording of BV1's hull timbers, dozens of hair samples were taken from the area between the hull planking and the sheathing (Fig. 7). These samples were analysed at the Centre for Ecology, Evolution and Environmental Changes (cE3c) of the Faculty of Sciences of the University of Lisbon, where there is a working group dedicated to the study of wolf ecology and conservation, focusing on predator/prey relationships. According to the known historical sources for the period concerned in the present study, the animals whose hair was mostly used for sheathing vessels were goats, sheep, cows, oxen, and horses. In other words, their common feature is that they are potential prey for wolves. Combining all these premises, we considered that a partnership would make sense, to identify the animal hair used in BV1 ship, and so it was. The samples were identified as horse hair.

Animal pelage consists of two types of hair: the protective hairs that are part of the outer covering and the fur or wool that constitutes the inner covering; the basic composition of an animal pelage is a mixture of both types (Valla-Pinto 1978; Deedrick and Koch

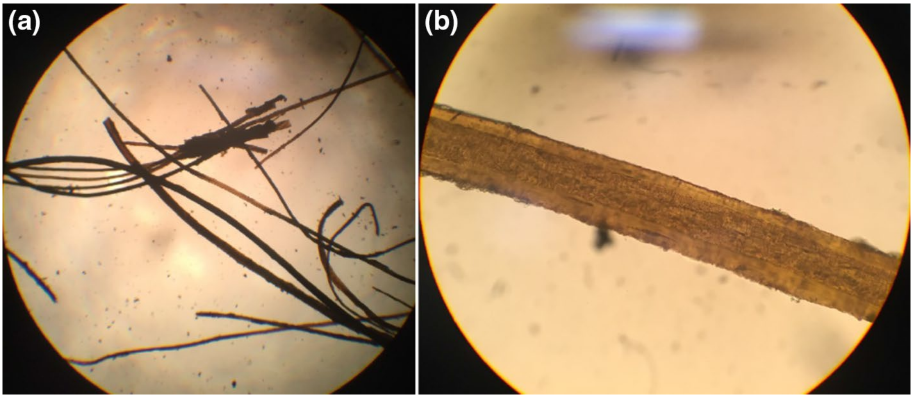

Fig. 8 (**a**) Overall view (**a**) and medulla (**b**) of the analysed hair (photographs by the authors)

2004, pp. 1–2). Only the protective hairs display certain diagnostic markers that allow the identification of a particular species of animal (Valla-Pinto 1978). The hairs on the inner covering of a particular species can easily be mistaken for the hair of another species if not examined by an expert with some experience.

Hairs are keratinised epidermal filaments of variable length consisting of a root and a shaft, an extension of the former, emerging on the outside of the dermis. The morphology of the shaft and its dimensions have considerable variations, ranging from the very simple hairs of insectivores to the hairs modified into spines of the box hedgehog, including a series of intermediate forms of strong consistency that form the mane and tail of some mammals, and the vibrissae or tactile hairs.

Hairs have two distinct functions: sensitivity and protection. There are two main types of protective hair. Some are small, thin, flexible, wavy all over and much more numerous in winter than in summer, providing protection against cold and humidity (woolly hairs); others are longer and thicker, straight, or slightly wavy and, unlike the previous ones, have a tapered end called covering hairs. Protective hair shows a structural consistency between the dorsal and ventral zones of the animals' body. The shape and arrangement of the cuticle scales, the relative thickness of the cortex, the number and arrangement of the medulla cells, and the contour of the hair, define distinctive characters in families, genera, or even species (Valla-Pinto 1978).

Although the different types of hair can show considerable differences, in structural terms they are made up of three concentric layers of keratin. The outermost is the cuticle, which is basically a very thin coating that surrounds the hair. Next is the cortex, the intermediate layer of variable thickness situated between the medulla and the cuticle. Finally, the innermost and central layer of the hair is the medulla, which can have different thicknesses, being composed of one or more layers of cells (Valla-Pinto 1978). The identification of hairs, which may reach the species level, is achieved through the microscopic analysis of the shape and arrangement of cuticle cells, the relative thickness of the cortex and the number and arrangement of medulla cells, in the proximal, mesial, and distal regions of the protective hairs, from the same area of the body of mammals.

In the case of the sample analysed (EDP_0198) (Fig. 8a), besides the macroscopic observation of the hairs, the characteristics of the cuticle and medulla were also evaluated. For the identification of the cuticle cell type, following dehydration the sample was glued into small aluminium stubs 1 cm in diameter, using adhesive carbon tape, and metallized using a JEOL JFC-1200 Sputter Coater with a gold target; observation was conducted on a SEM JEOL JSM 5200LV scanning electron microscope. For the identification of the medulla cells, a simple arrangement of the hairs in water was observed under the optical microscope, at 40x magnification, after degreasing and drying.

In the examined hairs, the medulla is readily visible. Its cells are arranged in a grid shape, and the cuticular impression is a simple mosaic in the proximal zone, gradually changing to a wavy mosaic in the mesial region (Fig. 8b). Hence, these features correspond to a typical equine hair, more specifically to a horse's mane.

Equine hair is rare in nautical archaeological contexts. It has only been found on the Newport ship, *Zeewijk* and BV1 shipwrecks. Goat hair was identified on the Newport ship, which featured a mixture of various hair types, on the *Batavia* and the *Vergulde Draak* ships. Cattle hair was identified on the Newport ship, the *Zeewijk* and the *Vergulde Draak* (Van Duivenvoorde 2012a, pp. 243–246). The Barrel Wreck featured a very thin layer of unidentified animal hair mixed with a resinous substance (Van Duivenvoorde 2012b, p. 13).

Conclusion

The BV1 ship provides an important dataset to the corpus of Portuguese ships found in archaeological context. The "architectural signatures" observed on its hull are commonly found in the maritime area of Mediterranean tradition, although there are no clear parallels in any remains published to date in Portuguese, Atlantic, or Mediterranean contexts. Its planking was attached to the frames by iron nails driven through pre-drilled holes in the planking and frames, usually placed on the ends or near the edges of the planks, which is characteristic of Mediterranean shipbuilding. On the other hand, there was an absence of wooden pegs, a Northern European characteristic. The majority of these nails have a square section and a circular head embedded in a previously pre-drilled countersink.

Moreover, the keel is composed of two or three sections, connected by butt joints, and there are two semicircular notches, one in each section, to fit pegs (stop water system). This characteristic, probably of Mediterranean origin, is rare both in the literature and in the international archaeological record, being mentioned in the 1618 *Ordenanzas* (Hormaechea et al. 2018, pp. 68–73) and in the 1691 *Traité de la Construction des Galères* (Rodrigues et al. 2001). Mediterranean parallels can be found in the *Sorres X* (Catalonia, fourteenth century), *Culip VI* (Catalonia, mid-fourteenth century), and *Mortella III* (Mediterranean France, sixteenth century) ships (Hormaechea et al. 2018, pp. 70–71). This same technique also appeared, however, in the Iberian-Atlantic ship of Cais do Sodré (Castro et al. 2011, p. 334). The existence of hook scarves in the joints between the frames and the futtocks, and the use of iron nails to reinforce these joints, as opposed to the combination of iron nails and wooden pegs used in the Iberian-Atlantic tradition, once again indicate Mediterranean tradition.

The BV1 ship also featured a layer of horsehair applied over the hull planking to protect it. It was not possible to determine whether the hair was mixed with pitch or any other compound, because the whole context was contaminated with naphtha, which made several laboratory analyses unfeasible. The use of horsehair as a waterproofing agent on ship hulls has been archaeologically confirmed since at least the fifteenth century. As seen previously, the Dutch shipwrights used this technique repeatedly for ships sailing to the Far East, staying at sea for many months, exposed to all kinds of wear and tear. In addition to the horsehair, the BV1 ship also had a layer of sacrificial sheathing that was attached to the hull planking by means of small square iron nails, mainly placed near the edges of the planks. Therefore, in BV1 ship, constructive details from both shipbuilding traditions coexist and new ones are forged.

The BV1 ship probably was a small- to medium-sized ship, with an overall length of about 20 m. Thus, its degree of protection seems somewhat disproportionate since it was not supposed to endure so many months at sea. Hence, we would hypothesize that these protections were related to the fact that the BV1 ship was a ship at the end of its life, having already made many voyages, and therefore in poor condition. In an attempt to extend its life by a few more years, a sheathing was added, and a thin layer of horsehair was applied in the gap between this sheathing and the external planking to improve its watertightness. The oak used in the construction of the ship, despite not being an architectural signature, not in its broadest sense, made it possible to point out a possible area of origin. In fact, the dendrological analysis allowed us to deduce that the oaks used in BV1 ship had a fast growth, being part of not very dense forests or with not very big trees, where they had the opportunity and space to grow and develop. At the same time, this forest had high sun exposure as well as relatively low precipitation levels. In other words, it is quite possible that the oak trees in BV1 ship belonged to some forest patch in the Iberian Peninsula, or other countries from the Mediterranean hydrographic basin.

Moreover, the archaeological evidence, together with the written, iconographic and cartographic sources, informs that on the chronology to which BV1 ship belongs (last quarter of the seventeenth century/first years of the eighteenth century), Boa Vista area was a very dynamic centre of Lisbon, where maritime and trading activities acquired a fundamental role. From the middle of the seventeenth century, with the creation of the *Junta do Comércio do Brasil*, this part of the city grew exponentially around the maritime activities, very much related to the Atlantic trade of the Portuguese empire. This is undoubtedly the most likely context that justifies the presence of BV1 ship in this part of the city, in this chronology, and reinforces the possibility that it was an agent in the Portuguese Atlantic trade, in the transition from the seventeenth to the eighteenth centuries. Nevertheless, as in all scientific studies, there are no absolute certainties, and obtaining certain answers inevitably lead us to ask new questions.

BV1 ship is a unique and essential resource for the study of shipbuilding in the post-medieval period, because *"History does not keep the memory of shipbuilders as much as it keeps that of palace builders"* (Matvejevitch 2019, p. 79).

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Declarations

Conflict of interest The authors are required to disclose financial or non-financial interests that are directly or indirectly related to the work submitted for publication. The authors declare that they have no conflict of interest.

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