Reconstructing Trees from Ship Timber Assemblages Using 3d Modelling Technologies: Evidence from the Belinho 1 Shipwreck in Northern Portugal

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Abstract
During the winter of 2013/14 a number of violent storms and related surges exposed a remarkable shipwreck site—tentatively dated to the early or mid-16th century—containing a timber assemblage, hundreds of pewter plates and other artefacts on Belinho beach, near Esposende in the north of Portugal. An international team was assembled including archaeologists from the Esposende city council and researchers from the ForSEA discovery Project. The objective of this project was to join a number of different experts and explore innovative methodologies to record and analyse ship timbers with forest management and timber supply networks in the Age of Discoveries.

A key recording strategy included the use of a Faro-Arm digitiser to record wood grain and timber conversion, together with photogrammetry, which was used to represent the timber surfaces. The compounded digital models were processed with Rhinoceros 3D modelling software. The collected data allowed researchers to model and develop reconstructed parent tree shapes from each ship timber, and try to better understand tree growth patterns, possible forest management activities, and timber selection for one of Iberia’s major post-medieval industries: shipbuilding.

The Belinho 1 Project is an ongoing experiment where an array of techniques is being tested with the involvement of the local community, in order to help us understand the Iberian shipbuilding world, share our discoveries as widely as possible, and let the technologies utilised interact and invite new questions and ideas, and hopefully produce a methodology to identify tree selection methods, conversion techniques, as well as shipbuilding practices and philosophies.

Keywords
Maritime archaeology, dendrochronology, tree reconstruction, computing, shipbuilding

Introduction
During the winter of 2013/2014, unusually large storms impacted the north coast of Portugal, provoking pronounced erosion along some stretches of sandy beaches. These storms exposed a remarkable archaeological find and sent a large collection of ship timbers and artefacts ashore (Figure 1).

These artefacts were first discovered by sculptor João Sá while looking for raw material during a walk on the beach. The artist accidentally spotted human-made shapes in the timbers nested among rocks. With the help of his family Mr Sá started to collect a variety of artefacts at low tide. Given the relevance of the artefacts found he contacted local and national authorities.

Archaeologists from the city council of Esposende promptly ensured the recovery and protection of the artefacts washed ashore. Soon after the discovery it became evident that the artefact collection encompassed two chronological horizons:
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- Belinho 1: A post-medieval (disarticulated) site including the remains of a ship’s hull, pewter plates, copper-alloy plates with relief figures, and a small number of personal artefacts, possibly dating to the middle of the 16th century.
- Belinho 2: Hundreds of Roman amphora fragments.

Previous work

In 2014 researchers from the Portuguese Centro de História d’Aquém e d’Além-Mar (CHAM), Universidade Nova de Lisboa, undertook a preliminary study of the post-medieval artefact collection under the direction of José Bettencourt, focusing on the key structural timbers that included the keel, stern knee, stern post, several floor timbers and hull planks (Bettencourt et al. 2014).

CHAM’s team concluded that:

1. The surviving architectural signatures on the Belinho 1 ship timbers are consistent with early modern Iberian shipbuilding technology (Castro 2008; Oertling 2001).
2. One curved timber was used to connect the keel, stem, and sternposts (couce and possibly coral).
3. The keelson was almost surely notched over the floor timbers and the mast step was an enlarged portion of the keelson.

Following the announcement of the finding of the Belinho 1 shipwreck site, historian Amândio Barros conducted an archival investigation to identify potential historical events related to the Belinho 1 loss. His research focused on the Esposende area, near to the beach of Belinho, during the late-16th and early-17th centuries. The research yielded an interesting candidate: a small merchantman with 70 to 80 tons in capacity, named Nossa Senhora da Rosa, lost in the area during the winter of 1577. This ship was built at Massarelos, a parish of the nearby city of Porto, using trees from the surrounding forests, by the carpenters Fernão D’Aires and António Eanes. Further research uncovered documents that mention the salvage of part of the cargo on 14 March of the following year, from the Belinho beach. Nossa Senhora da Rosa was sailing from the Canary Islands to nearby Vila do Conde with a cargo of pitch and Madeira wine (Barros 2016).

The artefacts found on this site since do not support this hypothesis. The copper-alloy plates seem to indicate a northern origin for the ship, the pewter plates have...
crowned hammer marks typical of the German Swiss region, and the guns seem to suggest a tentative date for this shipwreck somewhere between the first and the third quarters of the 16th century (Almeida et al. 2017).

**Belinho 1 research project**

Given the significance of the Belinho 1 artefact collection, the city council of Esposende invited a team of maritime archaeologists and wood science experts from the Marie Curie project ForSEAdiscovery (2013–2017; Grant agreement no.: 607545) to continue CHAM’s preliminary study, in the summer of 2015.

The evaluation of the Belinho 1 timber assemblage was carried out with four main objectives in mind (Martins et al. 2015):

1. To establish a date and provenience for the ship and its cargo;
2. To reconstruct the parent trees from the archaeological evidence, in order to try to understand timber growth patterns and ranges of shapes preferred by shipbuilders;
3. To develop dendrological studies on the Belinho 1 timbers (wood anatomy and dendrochronology); and
4. To develop a three-dimensional digital ship reconstruction based on timber shapes and other archaeological evidence.

The project was designed in accordance with Historic England’s guidance on project design MoRPHE and the Direção Geral do Património Cultural (DGPC) archaeology code of practice.

The methodology was chosen to maximise efficiency given the short available time for fieldwork. Thus, multiple work-stations were established in the area where the municipality stored the timbers in specially designed tanks. Archaeologists and wood scientists implemented a set of parallel activities to record and interpret both timbers and artefacts.

The pewter plates were photographed, drawn, and scanned for maker’s and possession marks under the microscope. The timbers were tagged, separated by function and recorded. The recording was carried out in three separate ways:

1. Morphological analysis: a fiche was filled for each timber and its conversion and special characteristics noted;
2. Wood grain: a FARO-Arm was used to record the most prominent grain patterns apparent of the timber surface, and digital photography to create 3D meshes of the timber surfaces with PhotoScan software; and,
3. Construction features: the shape, measurements, scarves, fastening patterns, and caulking solutions were manually recorded at a 1:10 scale, photographed, and described in individual fiches.

This methodology allowed different teams of researchers to rotate the timbers and work full time. The comprehensive documentation and recording process of individual timbers entailed unique labelling and the use of timber recording sheets (TRS) (Nayling and Jones 2014: 243); traditional recording techniques (Mckee 1978; Mardsen 1978; and Tremain 1978); 3D meshes (Jones, Nayling and Tanner 2013); computer vision photogrammetry (Yamafune, Torres and Castro 2016) and the collection of timber cross-section samples by hand-sawing. This workflow resulted in:

1. The recording of eleven key-structural hull timbers—seven Y-frames (BEL01-001W, BEL01-032W, BEL01-036,037W, BEL01-039W, BEL01-040W, BEL01-043W) keel (BEL01-071W), mast step (BEL01-051W), stern knee (BEL01-072W), stern post (BEL01-073W), and one floor timber (BEL01-003W)—with a FARO-Arm in a format adapted from the manual produced by Toby Jones (2014);
2. All the 75 timbers that composed the collection were photographed and recorded using direct measurements, computer vision photogrammetry, and hand sketches; and,
3. Twelve oak samples were collected from timbers displaying more than 50 rings.

Post-recording laboratory analysis undertaken by ForSEAdiscovery Project researchers led to the development of a dendrochronological report (Domínguez-Delmás et al. 2015a: 1; Domínguez-Delmás et al. 2015b), a detailed catalogue of the timber assemblage (Castro et al. 2015) and the editing and printout of the eleven individual timber’s 3D digital models, essential to developing advanced studies on tree and ship reconstruction of the Belinho 1 (Martins et al. 2015).

**Data analysis**

The digital models of each of the selected timbers were used to produce working files that better represented the morphology and the final shape of each of the eleven key-structural hull timbers. The original 3D files were first edited in Rhinoceros to remove irrelevant lines and ensure that all lines were associated with the correct layers, both in terms of the faces represented and the attributes assigned. The edited files provided clearer 3D reproductions of the eleven individual timbers and were used as the basis for another series of new files. In order to produce 2D traditional drawings,
each face was projected onto an orthogonal plane. This task produced a set of 2D orthographic projections of each timber face, complemented with cross-sections (Figure 2).

The drawings developed were produced by merging the 3D models with the photogrammetry data, and adding the information collected through inspection on the timber recordings sheets, and fieldwork notes. This task was aimed at highlighting construction features in each timber, namely the fastening patterns, scarves, caulking arrangements, sections and shapes.

Although none of the then 75 timbers was washed ashore in connection with any other timber, the angles of some of the outer planks’ hoods and the position of some of the fasteners allowed the matching of nineteen individual timbers, forming a portion of the ship’s runs (Castro et al. 2015).

A fourth type of drawing was produced from the edited files and used in the tree reconstruction process. On these files, the layers containing the wood conversion were hidden, and the natural wood features were highlighted (this process will be explained in detail in the section on tree reconstruction below). In this way, the drawings obtained reproduce a set of diagnostic features with precision, revealing growth patterns, natural edges, branches, and knots.

Sample collection, wood identification, and dendrochronological results

After completion of the recording process, a selection of timbers was sampled by either coring or sawing, yielding a total of fifteen samples. Sampling was performed with care to minimise its impact on the timbers. Increment borers were used to sample timbers which possessed good dendrochronological potential, namely substantial number of tree-rings and presence of sapwood, but which would lose integrity if sampled with a saw. The remaining elements were sampled by sawing their ends, thus, mitigating the impact on the integrity of the timbers. Wood samples were sent to different laboratories within the ForSEAdiscovery network where they undertook a variety of analyses, particularly for dating, wood anatomy studies, and geochemical analysis purposes.

The visual inspection of the samples allowed the identification of twelve of them as deciduous oak (Quercus subg. Quercus). Two other samples correspond to conifer species, although the observation of anatomical features with a microscope in the radial section has not led to the identification of the timber species. Finally, one sample from a timber of uncertain origin (possibly not part of the ship structure) was found to belong to a tropical species and was excluded from further analysis.
Only five of the twelve samples identified as belonging to the oak group were considered for dendrochronological analysis, as they contained more than 80 rings, with six samples having less than 60 rings (Figure 3). Two of the samples (from plank fragments BEL01-013W and BEL01-024W) with most rings showed a very strong statistical and visual crossdating with each other (correlation coefficient: 0.64; Student's t-value: 8.95; percentage of parallel variation, %PV: 74.5%; significance level of the %PV: p<0.001; overlap: 104 years). This indicates that the timbers were very likely derived from the same parental tree possibly fragments from the same timber). The lack of more internal matches with and between the other samples, together with the strong variability in growth rates (i.e. mean ring widths in the oak samples range from 0.60mm to 2.62mm per year), indicates that the wood could have been sourced from different areas, or from a large area where tree growth rates varied. Another explanation for the lack of matches between the timbers could be that the samples are not contemporary, i.e. some timbers could be repairs. Furthermore, the fact that the ship timbers had washed ashore hinders the certainty that all timbers here examined are part of the same wreck. This makes drawing conclusions challenging, especially for the tropical timber present among the samples, which cannot be regarded with certainty as a part of the ship’s assemblage (Domínguez-Delmás et al. 2015b).

The comparison of all the tree-ring series with European reference chronologies and oak chronologies from the north of Spain have failed (for the moment) to produce statistically sound results. Therefore, all samples remain for now undated, and the provenance of the wood remains unknown.

**Ship timbers**

Due to the high-level of erosion caused during site formation process, some key features such as scarves, timber edges and original surfaces were eroded in many timbers. Despite this problem, the characteristics of some timbers and the fastening patterns suggest a possible origin for this ship in the north of the Iberian Peninsula. Below is a quick characterisation of the ship timbers recorded in the summer of 2015.

**Hull Timbers**

A total of 75 timber fragments washed ashore from 2013 to 2015. As mentioned above, they were divided into five groups, according to their purported structural function (Castro et al. 2015).

**Longitudinal structure**

The first group consisted of timbers from the longitudinal structure and encompassed portions of the keel (BEL01-071W), sternpost (BEL01-073W), stern knee (BEL01-073W), and mast step (BEL01-051W).

The keel segment preserved was rabbeted (around 8.5cm), measured 879cm in length and its section was 22–24cm sided and 19cm moulded. There were no signs
of scarves on either end of the keel segment. Twelve 2.7cm circular bolt holes were preserved along with the timber length, connecting some floor timbers to the keel, spaced around 70cm on average, if we exclude the distance between bolts 5 and 6, which was 115cm. The bolt heads, with diameters around 5.5–6.0 cm, were lodged in countersunk holes 6–7cm in diameter, and 2.5cm deep. Marks of 1.1cm square iron nails, fastening the garboards to the keel, were preserved along the rabbets, and spaced 70cm on average. The fasteners' pattern on the planking suggested a room and space around 35cm and indicated that the keelson was bolted to this portion of the keel through every other floor timber, except between bolts five and six where there were probably two-floor timbers between bolts.

The sternpost segment was preserved along 290cm, and its section was 20cm sided and 21cm moulded. Three 2.7cm bolt holes were preserved, spaced 70cm and 53cm, which correspond to the spacing of the bolt holes preserved on the stern knee (coral). The deep rabbets (31.4cm deep) presented 1.1cm square nail holes and 2.5cm preserved treenails, which fastened the hood ends of the hull planks to the sternpost. These fastening holes allowed the re-positioning of seven hull planks, which had washed ashore separately. The after face of the stern post preserved nail marks that suggest that the sternpost was covered with sheathing, and a protruding tenon with two diagonal nail holes the function of which is not yet clear.

A stern knee washed ashore as well, 281cm long and 20cm high. Its moulded dimension varied between 12.3cm and 8.7cm and its sided dimension was 20cm. Four iron bolts indicate that it was fastened to the keel although the spacing of these bolt holes does not correspond with those found on the surviving fragment of the keel. In contrast, three bolt holes on the upper part of the stern knee match those on the sternpost. Again, two or three 11mm square nail holes, and two 25mm treenail remains indicated the fastening pattern of the hull planking to the stern heel side faces.

The remains of a mast step bear signs of long exposure to the actions of marine life and were heavily eroded. It is an expanded portion of the keelson, 197cm long, 45cm sided, and 30cm moulded. The step mortise is 86cm in length, 18cm sided, and 10cm deep. Two bolt holes allow a tentative positioning of this portion of the keelson between the 7th and 8th bolt holes of the keel. The mast step is notched to fit over the frames.

Transversal structure

The second group of timbers found at the Belinho 1 site included seven Y-frames (picas), five floor timbers, three frame fragments that appear to be the lower extremities of first futtocks, two timbers that were tentatively identified as fragments of deck knees, and a broken frame fragment.

The central framing timbers presented square sections around 18cm sided and moulded, and the same pattern of nails and treenails for the fastening of the hull planking. They showed central trapezoidal limber holes positioned slightly to the side of the keel axis, and some had dovetail joints in the preserved extremities, in the area overlapping with the futtocks. The floor/futtock fastening pattern seems to have been two treenails and two iron nails.

Floor timber BEL01-045W did not have an apparent dovetail scarf on its preserved arm but showed a step on the face opposite to the futtock, where a nail was inserted, in a manner similar to those found at Highborn Cay (Oertling 1989). Floor timber fragment BEL01-041W presented a foot with a central limber hole and only one treenail mark, on its foreword and after faces. One of its arms seems to have been around 30cm long, suggesting that this timber may have been a reinforcement placed between the inner extremities of two first futtocks, reinforcing the floor timber in the keel area. Floor timber BEL01-042W presents similar features to the timber described above. The maximum length surviving has 321cm, and its section was 17cm sided and 18cm moulded. On one of the sides this timber has a dovetail scarf measuring 23cm on the top and 28cm on base. Evidence shows that at least one nail was inserted on the futtock through is step. The floor timber also possesses an inscription 'II', which probably indicates its location on the framing system.

The futtock extremities preserved varied in length, mostly near 1m, and presented sections 16–18cm sided and moulded. Some of the futtocks showed dovetail scarves with a pattern of two or three nails and two or three treenails in the floor/futtock connection. The two purported deck knees are eroded pieces with fastening patterns and notches that suggest this function, but so far it is not possible to definitely identify them as such.

Stern planking and other longitudinal timbers

The third group of timbers washed ashore at Belinho included a portion of a waterway, three fragments of port side hull planks with their aft hoods preserved, four fragments of starboard hull planks with their aft hoods preserved, and five plank fragments difficult to position at this stage.

Planks BEL01-053W, BEL01-056W, BEL01-060W, and BEL01-059W angles, fastening holes, and dimensions match the marks and angles on the starboard side of the sternpost. Similarly, planks BEL01-055W, BEL01-054W,
and BEL01-057W match port side angles and fasteners’ marks of the sternpost (Castro et al. 2015).

A curious feature observed in these hull planks is that they were carved with triangular notches 5–7mm deep, and grooved on their outer surfaces coated with a resinous substance, and sheathed with either lead or sacrificial wood, although no traces of lead were picked up in several XRF analyses performed on coating samples (Castro et al. 2015).

Has expected, the planking conversion type presents evidence of tangential conversion, although at this time it is not possible to identify which tools were used for the process. The level of erosion affected the timbers’ surfaces, and made difficult to identify tool marks, although some carpentry marks, such as the number ‘II’ on floor timber BEL01-042W.

The group of the twelve best preserved hull planking timbers was cut from oak trees bearing a maximum of 128 tree-rings and a minimum of 36 annual rings. One of the eroded timber fragments from this group (BEL01-061W) was sampled for dendrochronological analysis. It was not possible to identify the Quercus sub-species at the present stage of the project. Planks BEL01-053W, BEL01-056W, BEL01-060W, BEL01-059W, BEL01-055W, BEL01-054W and BEL01-057W, already mentioned above, do not show evidence of large knots, suggesting that they were cut from straight stem trees.

**Plank Fragments and unidentified wood**

The fourth group of timbers consisted of 27 small fragments of planks, impossible to place in any particular position in the hull at this stage of the project (Castro et al. 2015). A fifth group consisted of 11 small fragments of wood from unidentified timbers, also impossible to a position at this stage of the project (Castro et al. 2015; Figure 4).

**Tree reconstruction**

As already mentioned, the Belinho 1 timber assemblage suffered significant levels of erosion, which increased the difficulty of the recording process. Despite this, the timbers analysed offered relevant data for advanced dendrological studies. The seven Y-frames, a complete floor timber, the stern knee, the sternpost, a portion of the keel and the fragment of the keelson (mast step) were selected for careful recording using digital techniques due to their potential to provide relevant data for tree reconstruction.

Evidence of knots, cracks, and growth patterns was used to plot the location of the timber pith along the full length of each timber. The tree-rings visible at end of the Y-frames clearly indicated the points where the tree stem split into two or more branches. The grain lines on the floor timbers were useful for identification of the curvature of the parent tree.

The timber recording methods employed, both manual and with a FARO-Arm, reproduced with precision the wood features that led to the tentative tree reconstructions. The 3D digital models produced followed specific recording protocols, which enabled the identification of exact angles of curvature, and potentially diameter of the parent trees, in comparison with the shape and size of the selected individual timbers. This method proved to be effective and allowed us to identify the particularities of the parent tree of each timber, namely ring widths, grain curvature on the main stem, as well as position, density, and angles of branches.

As mentioned above, once the 3D digital models were edited and re-inspected, it was possible to hide the layers related to the work performed by the carpenters with Rhinoceros software. The resulting models represent only the wood features, which give a clear view of the wood anatomy on each timber surface. The grain lines and the inclination of the knots are essential to identify the direction of the tree (roots and canopy). Once the growth direction is identified, the next step is to find the pith location in the stem and branches, which was possible in the case of the stern knee and Y-frames. The maximum width can be defined by the pith and the preserved waney edges on the timber surface. The ring-width and natural heartwood edges can also provide additional information. After achieving the maximum
width on each surface and identifying the growth direction, it is possible to recognise the shape of the tree and some of its morphological characteristics. Sapwood was only observed on timber BEL01-001W, which made it impossible to identify the maximum diameter of each timber. Either bark and sapwood removed during woodworking, in keeping with the advice given in broadly contemporary shipbuilding treatises, such as the *Liuro da Fabrica das Naos* (Oliveira c. 1580), or the *Livro Primeiro da Architectura Naval* (Lavanha c. 1600), or it was lost, eroded after the shipwreck.

The Belinho 1 ship timbers were tangentially cut from the parent trees and then shaped using a variety of tools to meet the required shape. The Y-frames presented shapes consistent with the transverse and longitudinal angles of the hull. The Y-frames’ feet were cut at angles that fit over the stern knee where they stood, and their height formed a plausible shape of the transition between the ship’s runs and the wider portion of the upper hull in that area. The progression of the angles of branches of each of the Y-frames positioned on the inboard face of the stern knee showed a consistent pattern and formed a smooth, fair and, thus, plausible shape of that part of the hull:

- Y-frame BEL01-037W angle of the branches is 3°, the length of the stem 99.2cm, abundant knots along the stem;
- Y-frame BEL01-036W angle of the branches is 8°, the length of the stem 148.3cm, not having knots along the stem;
- Y-frame BEL01-039W angle of the branches is 12°, the length of the stem 145.7cm, abundant knots along the stem;
- Y-frame BEL01-001W angle of the branches is 22°, the length of the stem 149.2cm, not having knots along the stem;
- Y-frame BEL01-040W angle of the branches is 24°, the length of the stem 127.1cm, abundant knots along the stem;
- Y-frame BEL01-043W angle of the branches is 21° but reduces the length of the stem to 83.9cm, abundant knots along the stem; and,
- Y-frame BEL01-032W angle of the branches is 15°, the length of the stem 184.6cm, not having knots along the stem.

The longitudinal structural timbers revealed the following features:

- To shape the stern knee carpenters needed a tree with a larger stem and branches having an angle of about 105° between each (in comparison the timbers previously mentioned); and,
- To obtain the keel carpenters needed a long tree with the minimum of 900cm in length and 22.3cm in width. This timber also presents a larger branch on its inboard face. Many other relatively small size branches can be observed along each surface of the keel full extension.

Evidence has also shown that to build the Belinho 1 ship carpenters needed at least four types of trees:

- **Y-frames**—straight stemmed oak trees ending with at least two branches in the canopy forming symmetrical angles from vertical;
- **Floor timber and futtocks**—long stem or branches having a smooth curvature;
- **Stern knee**—large stem and branches with an angle closer to 105°; and,
- **Keel**—long straight stem having the minimum of 900cm in length.

At this stage, this study allowed the following conclusions:

**BEL01-001W (Y-frame):**

- Minimum diameter of the stem is 74cm, minimum diameter of the port side branch is 18cm, angle of the stem to the branch is 15°, the minimum diameter of the starboard side branch is 21.4cm, the angle stem to the branch is 156°, and the maximum length of the stem with the absence of knots is 149cm;
- The absence of knots along the main stem;
- Specific V-shape of the canopy;
- The width of the stem is consistent with the other timbers in the ship’s stern;
- The pith, growth pattern and the split of the stem into two branches provided the shape required for ship construction;
- The growth rate (i.e. average ring width) is consistent with higher levels of moisture (precipitation/groundwater levels); and,
- The sapwood was removed to shape the timber, but the heartwood seems to preserve its maximum extent (some traces of sapwood).

**BEL01-003W (floor timber):**

- Clear growth orientation of the timber (crown/stem);
- The abundance of knots at one end;
- The curvature of the timber is consistent with the natural curvature of the tree;
- Fast-growing timber suggests a landscape abundant in water and minerals;
- The grain at the lower end of the timber suggests the existent of forest practice to encourage the growth of multiple branches (pruning/pollarding); and,
At the bottom of the timber, the growth pattern is consistent with forest management techniques.

The process of tree reconstruction involves a complex data analysis in which every wood feature needs to be carefully inspected. In this particular case it is a still ongoing study, undertaken within author Miguel Martins' doctoral studies as a Marie Curie-ForSEAdiscovery Project fellow.

Timber analysis requires that archaeologists acquire experience in both shipbuilding characterisation and dendrology. The recording process should aim at acquiring compounded information related to shipbuilding and wood anatomy. This study is a contribution to the development of a methodology that will hopefully become mainstream in nautical archaeology within a few years. The recording protocols we will develop in the incoming years will allow for new forms of 3D recording, manual samplings, visual observation, and any other methods available, such as X-rays or magnetic resonance. The 3D digitiser arm proved to be an extremely effective tool, mostly when compounded with Rhinoceros software. Budget and fieldwork time constrains most probably dictate that only a selection of timbers will be digitally recording and analysed (as was the case in the Belinho 1 Project).

We opted to convert the 1:10 scale drawings into 3D digital representations later, in order to manipulate the timbers and try to match them against an hypothetical model of the hull, developed from the only diagnostic measurements we could obtain from the archaeological data: the flat of the floor timber near amidships, and the probable height of the ship's runs. Our reconstruction is hypothetical and should looked upon as a preliminary attempt at making sense of the timbers that washed ashore at Belinho in 2014 and 2015 (Figure 5).

Conclusions

The main conclusions of this study can be summarised along two main lines. The first is that this study setup clearly the need for protocols to standardise the recording of both nautical information (Castro et al. 2018), and that these protocols must include dendrological analysis. The second is that although at this time neither archaeological nor dendrological evidence have shown a strong correlation between the Belinho 1 timber assemblage the shipwreck discovered in the archival research, there is no reason to change our methodology. Dendrochronological evidence has not yet yielded any matches, and the artefact collection doesn't seem consistent with the ship's route.

The studies carried out on the Belinho 1 ship timbers allowed us, however, to conclude that from the 12 samples that underwent dendrochronological research, both framing and planking elements presented fast and slow growth rates, suggesting that there was an unspecific selection of trees in terms of growth types for the construction of this ship. Although in order to draw conclusions relative to the quality of the timber supply we will need to carry out further analysis, this is an important piece of information the incomplete multidimensional puzzle that every shipwreck presents.

The tree reconstruction attempts carried out on the Y-frame BEL01-001W and floor-timber BEL01-003W allowed the characterising of their parent trees with a good degree of certainly, yielding information on the forest where the timbers originated from. Straight stems with a low number of knots were sought by shipwrights for their strength and are typical of trees that have grown in high-density stands.

The structural timbers analysed presented evidence of having been selected in accordance with the wood grain flow orientation to avoid cracking by tension, and show that both straight and compass timber—trees and branches—were available in the forests where they were cut.

The sample of deciduous oaks showing variable growth rates and lacking internal cross matches suggests that the wood was sourced from different areas or an extensive area where tree growth was variable. The growth pattern seemed to be consistent with oak trees of about 60 years (average of annual 50 rings plus rings lost by erosion, or removal sapwood and bark). The Y-frames also seem to be consistent in terms of growth pattern, and the floor timber and futtocks present the same correlation within each typology. Equally, the absence of a significant number of knots along the timbers presented evidence of the areas in which the trees were planted. The ring-width average has also demonstrated in which extent trees were supplied with abundant water and minerals (precipitation/groundwater levels).

As already mentioned, given the relatively small number of timbers sampled there is a possibility that some of the analysed timbers may not be contemporary, corresponding to possible repairs. Again, this piece of information is relevant for the ongoing study of the ship.

Although the nature of the Belinho 1 shipwreck site, located in a high energy area which poses serious risks to diving, has determined the slow pace of this study, mostly commanded by the atmospheric conditions and the natural movement of sediments of the bottom, the information already gathered allows us to emphasise the importance of this site. The ship timbers’ shape and assemblage techniques are consistent with an Iberian architectural provenance, and even though the
tentative chronologies established for the artefacts do not permit a tentative dating within a few decades, it is likely that this ship dates to the second quarter of the 16th century, making it a precious testimony to the European shipbuilding techniques of that time.

**Acknowledgements**

The realisation of this study was made possible by the collaboration of the ForSEAdiscovery Project team, Council of Esposende and Texas A&M University’s J. Richard Steffy Ship Reconstruction Lab.

'The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union’s Seventh Framework Programme (FP72007-2013) under REA grant agreement no. PITN-GA 2013-607545.'

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