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Morgawr: an experimental Bronze Age-type sewn-plank craft based on the Ferriby boats

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This paper reports on the construction of a full-scale Bronze Age-type sewn-plank boat based on the Ferriby boats. The boat, which was named *Morgawr*, was constructed in the National Maritime Museum Cornwall in Falmouth, England, during 2012 and the first months of 2013, as part of a larger exhibition in the museum. This paper provides the background and context of the project, describes the process of building the craft, and reflects in particular on differences between *Morgawr* and the 'hypothetical reconstruction of a complete sewn-plank boat' published in 1990 by Ted Wright and John Coates which formed the basis for this project.

Key words: National Maritime Museum Cornwall, rocker, withies, keelplank, cleats.

The sewn-plank boats from England and Wales constructed between *c.*2000 and 800 cal BC are the oldest-known planked vessels from Atlantic Europe. Their construction represents a remarkable development in regional boatbuilding technology. Using planks rather than hides or a hollowed-out tree-trunk brought about three concurrent innovations: first, in the absence of any nails or treenails, planks were sewn or stitched together with organic fibres of yew or willow; second, an intricate system of integrated cleats and slots or transverse timbers was employed to ensure stiffness of the bottom of the hull; third, caulking was used for the first time, made from woodland mosses.

None of the sewn-plank craft discovered in England and Wales to date are complete or near-complete. The remains of Ferriby 1, the Dover Boat and the Brigg 'raft' are substantial, to the point that their hull shape, size, performance and the seaworthiness of the original craft have generated extensive discussions and debates (for example Wright and Wright, 1947; Wright, 1985; 1990; Roberts, 1992; 2004; McGrail, 1985; 1994; 2007; Clark, 2004a; Coates, 2005; Crumlin-Pedersen, 2006a; Crumlin-Pedersen and McGrail, 2006; Sanders, 2007). Two sewn-plank boats have been constructed as half-scale models: the *Oakleaf* is a half-scale Ferriby-type model based on Edward ('Ted') Wright and John Coates' drawings of the reconstructed craft (Gifford

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and Gifford, 2004; Gifford *et al.*, 2006) and, most recently, the Dover Boat was reconstructed at half-scale to form a key component of the international exhibition 'Boat 1550 BC', and named *Ole Crumlin-Pedersen* (Darrah, 2012). The key advantage of building half-scale instead of full-scale models is a significant reduction in the building, maintenance, storage and crewing cost, by as much as a factor of ten; disadvantages of half-scale models are that these create misleading impressions of the size of the original craft (especially when these are crewed with full-sized humans), and the inability to test timbers, fixings and caulking in a scientifically meaningful manner because their material characteristics are not readily scaled (Gifford and Gifford, 2004: 67, 71).

The construction of a full-scale sewn-plank boat, which we named *Morgawr*—Cornish for 'sea monster' and, more specifically, the name of the Falmouth Harbour sea serpent—was the centrepiece of the exhibition '2012 BC: Cornwall and the Sea in the Bronze Age' at the National Maritime Museum Cornwall (NMMC), Falmouth (Fig. 1). Thus, one aim of this project, thereto funded by the Arts and Humanities Research Council (AHRC) under its Knowledge Transfer Fellowship scheme, was to reconnect communities with their distant maritime past and to provide the NMMC with a new, and potentially transformational, concept in engaging with the public and with the community of maritime researchers. In terms of visitor numbers, visitor feedback, reports in the media and development of museum staff, the project was considered an unqualified success. A parallel paper that focuses on the impact of the project on the NMMC and the public is in preparation. The integration of the construction of *Morgawr* within the exhibition provided museum visitors with an interactive display of a Bronze Age-type sewn-plank boat under construction. Funding for the reconstruction of a Bronze Age-type sewn-plank boat would not have been made available were it not for the educational (or 'Knowledge Transfer') focus of the project, something that has also been the case in other maritime archaeology reconstruction projects (for example Burningham and De Jong, 1997: 277).

While public engagement and knowledge transfer were primary objectives of the overall project, a critical aspect of the research was to appreciate more fully how boats may have been built in the Bronze Age. Our approach was through experimentation, more specifically to construct a Bronze Age-type sewn-plank boat and to gain new insights into the process of construction. This is the focus of this paper, which presents the results of the full-scale construction of *Morgawr*. As was the case with the construction of *Oakleaf*, the construction of *Morgawr* used as its principal reference Wright and Coates' 'hypothetical drawing of a complete boat' (hereafter referred to as the 'complete boat'; published in Wright, 1990: 85–116, and figure 5.17 in particular) (Fig. 2a). This paper provides a short background to the archaeological discoveries of sewn-plank boats in England and Wales and the role of Cornwall in Early Bronze Age trade and exchange connections; a description of the process of constructing *Morgawr*; and a description of *Morgawr* and a comparison with the 'complete boat'. The result of current and future seatrials will be published in a separate paper.

Figure 1. The exhibition '2012 BC: Cornwall and the Sea in the Bronze Age' in the National Maritime Museum Cornwall, with *Morgawr* at its centre. (Photo: Jon Bennett)

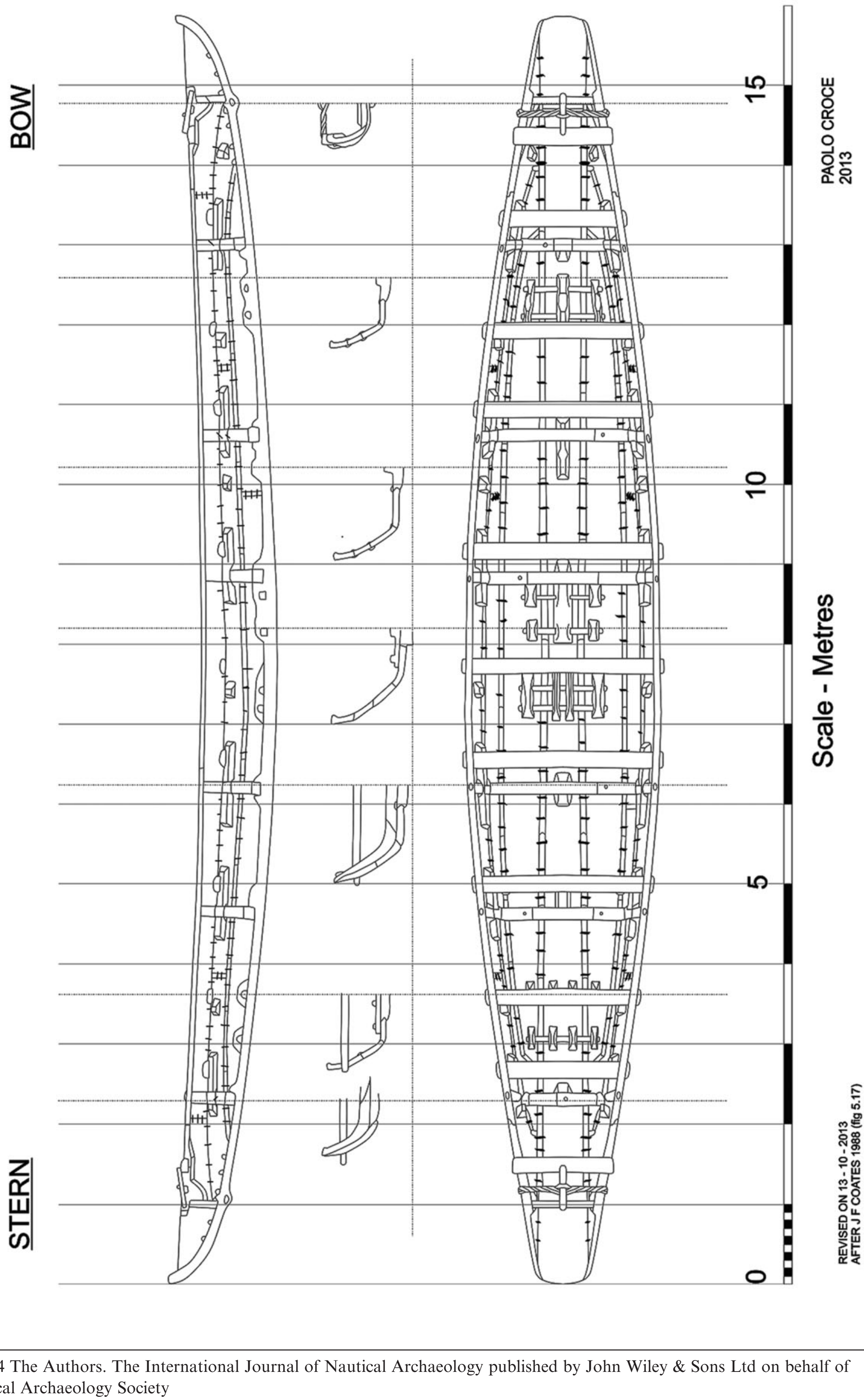

Figure 2. a) Line drawing of the 'complete boat', based on Ted Wright and John Coates' drawing (in Wright, 1990: 104–5), but redrawn, simplified and with the bow to the right. (Drawing by Paolo Croce; © Ferriby Heritage Trust)

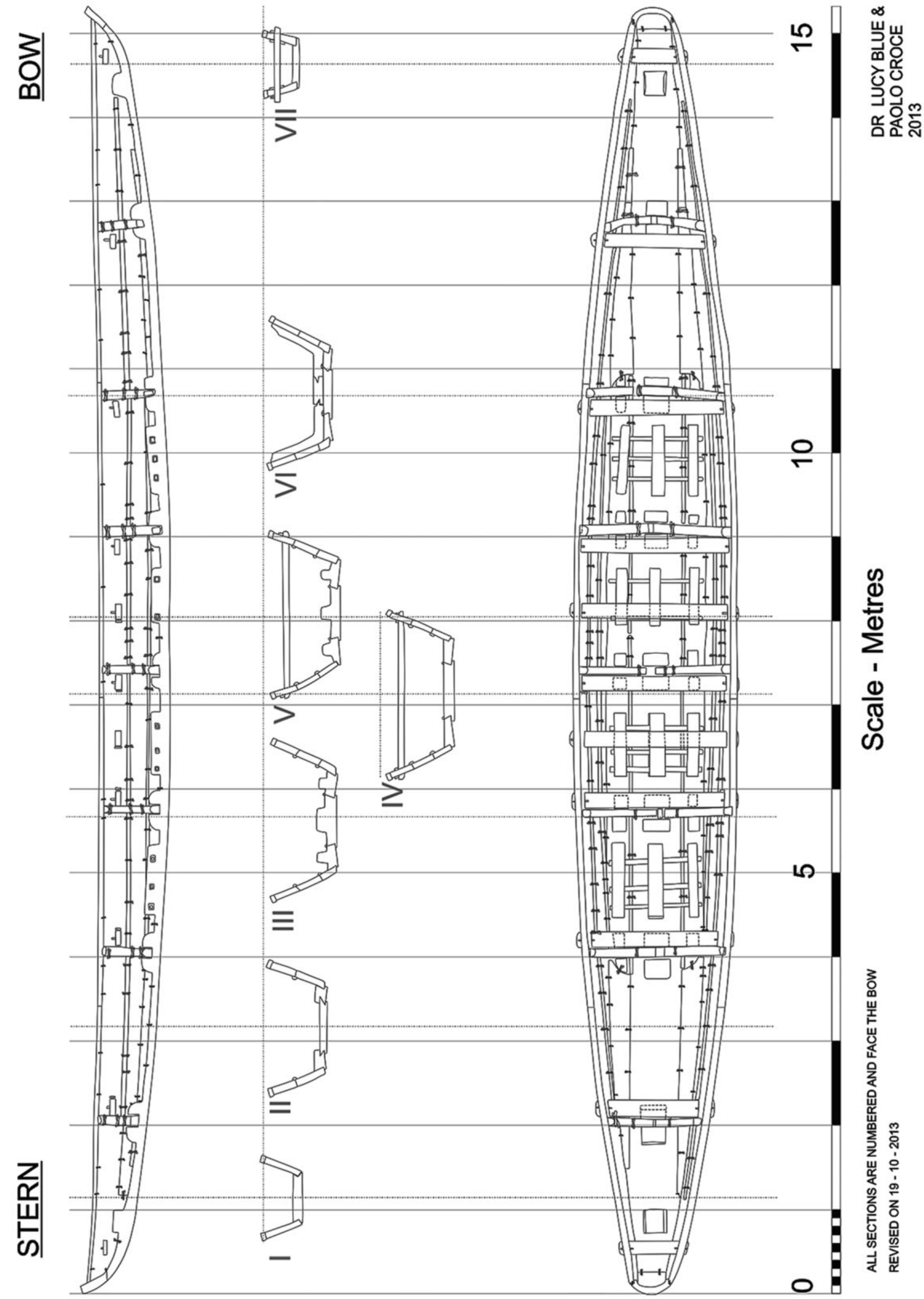

Figure 2. b) Archaeological plan of *Morgawr* (sections face the bow) (Drawing by Lucy Blue and Paolo Croce)

Sewn-plank boats and Bronze Age Cornwall

To date the—sometimes fragmentary—remains of ten Bronze Age sewn-plank boats have been found in England and Wales. From the Humber and its tributaries come Ferriby 1, 2 and 3, the Kilnsea boat and the Brigg 'raft' (McGrail, 1981, 2014; Wright and Wright, 1939; Wright, 1985; Wright, 1990; Van de Noort *et al.*, 1999). The remains of three sewn-plank boats come from the Severn: a fragment from Goldcliff and the remains of Caldicot 1 and 2 (Bell, 1992; 1993; McGrail, 1997). The two remaining finds are the Dover Bronze Age Boat (Clark, 2004a), and a cleat from Testwood Lakes on the River Test, a tributary of the Solent (Fitzpatrick *et al.*, 1996). The dates of these craft are listed in Table 1. The sewn-plank boats constructed before the 13th century BC, including Ferriby 1, 2 and 3, Dover and Caldicot 1, used individual lashings to fasten planks edge-to-edge. The planks of the boats build after the 13th century BC, including Caldicot 2, Goldcliff and the Brigg 'raft', used continuous stitching for this purpose (McGrail, 2001: 190). As yet, no (fragments of) sewn-plank boats dated to the Bronze Age have been identified outside England and Wales.

It is not improbable that the sewn-plank boats developed from skin or hide boats, adopting the sewing or stitching and the internal frame or skeleton from such hypothetical craft (Van de Noort *et al.*, 1999: 135; Van de Noort, 2011: 150). Alternatively, and in keeping with other sewn-plank boat traditions such as those from Scandinavia (Forssell, 1985), the extension of logboats through the addition of planks sewn to the gunwales is also possible. Either way, it seems highly likely that the Ferriby boats do not represent the first attempts to build large, plank boats. Certain practical solutions, such as the countersinking of the yew withy stitches to avoid erosive contact with the beach when landing such a boat, suggest that these craft had been developed over a considerable period of time, with the Ferriby boats benefitting from lessons learned from the construction of earlier sewn-plank craft.

Table 1. *The dating of the sewn-plank boats and boat fragments from England and Wales (after Van de Noort, 2006: 274)*

Sewn-plank boat	Date	Reference
Ferriby 3	2030–1780 cal BC	Wright *et al.*, 2001
Ferriby 2	1940–1720 cal BC	Wright *et al.*, 2001
Ferriby 1	1880–1680 cal BC	Wright *et al.*, 2001
Caldicot 1	1870–1680 cal BC	McGrail, 1997
Kilnsea	1750–1620 cal BC	Van de Noort, *et al.* 1999
Dover	1575–1520 cal BC	Bayliss *et al.*, 2004
Testwood Lakes	*c.*1500 cal BC	Fitzpatrick, pers. Comm.
Goldcliff	*c.*1170 BC	Bell *et al.*, 2000
Caldicot 2	*c.*1000 cal BC	McGrail, 1997
Brigg 'raft'	825–760 cal BC	Switsur in McGrail, 1981

The seafaring capability of these sewn-plank boats has been a matter of long-standing discussions, going back to the discovery of Ferriby 1 in 1937. Among maritime archaeologists, this debate has focused primarily on issues of transverse hull shape and rocker, whether frames were part of the construction, and if two or three side-strakes were required to complete the hull of Ferriby 1 (for example McGrail, 1987: 118; 1994; 2001: 186–7; 2007; Wright, 1985; 1990; Roberts, 1992; 1995; 2006; Coates, 2005). These issues are almost certain to remain unresolved, because the physical remains of the Ferriby 1, 2 and 3 craft have not survived in a condition that allows for the detailed analysis of these aspects of the sewn-plank boats.

The broader archaeological evidence shows that the Early Bronze Age was a period that witnessed a significant intensification in trade and exchange across seas. This is exemplified in the widespread distribution of different types of beaker pottery from the late Neolithic period onwards (for example Vander Linden, 2004), and in the distribution of bronze tools (for example Pare, 2000). Of course, this is in itself not evidence that sewn-plank boats were used for seafaring. However, the discovery of Kimmeridge shale from the Dorset coast in the Dover Bronze Age Boat has been interpreted as evidence for at least one journey of 120 nautical miles through the English Channel (Clark, 2004a; 2004b: 8). From a contextual landscape perspective it has been observed that, in contrast to Bronze Age logboats, the distribution of the sewn-plank boats is confined to the coast, estuaries or the tidal ranges of rivers, and this suggests that these craft may have been intended for use on the sea, as well as estuary crossings and in the intertidal zone (Van de Noort, 2006: 268).

While there are no finds of sewn-plank boats from Cornwall, the county, along with Devon, did play a central role in maritime activity in the Early Bronze Age. This activity might have been coastal, but it was also cross-Channel, as a number of finds show. One of the most famous objects from the Cornish Bronze Age is the gold cup from Rillaton on Bodmin Moor. This is one of a series of cups in precious materials (including silver and amber) that are found either side of the Channel in the Early Bronze Age, and which probably represent a single craft tradition spread across north-western Europe (Needham *et al.*, 2006; Needham, 2009). Another piece is a broken sword hilt from a barrow at Pelynt, apparently made in Greece, which somehow found its way to Cornwall. Such finds, by themselves, might not mean more than a haphazard passing on of objects from hand to hand, but when put into context the picture changes. Recent discoveries in the sea off Salcombe include ingots of copper and tin, as well as a series of tools, weapons and ornaments (Needham and O'Connor, 2013). This strongly suggests that cross-Channel voyages, especially connected with the metals trade, were a regular occurrence in the Bronze Age—and given the wealth of mineral resources in Cornwall and Devon, this is hardly surprising. Cornish tin supplied the continent of Europe in Roman times, and it has usually been supposed that this situation applied to prehistory as well (for example Quinnell, 1986).

This scenario has been put into high relief by recent analyses of the metals on the most famous Bronze Age find of recent decades, the Sky Disc from Nebra in central Germany. This extraordinary object, which shows a representation of the heavenly bodies, perhaps for astronomical predictions, is made of bronze with gold inlays. Analysis now shows that while the copper comes from the Austrian Alps, the tin and gold in all likelihood come from Cornwall (Haustein *et al*., 2010; Ehser *et al*., 2011). These facts confirm what the isolated artefacts such as the Rillaton cup have long suggested: that Cornwall was part of a large-scale and long-distance trade network, in existence since at least the Early Bronze Age. In this, boats like those from Dover and North Ferriby—the latter now represented by *Morgawr*—may have played a major role.

Project design

The aim of the experiment was to construct a full-scale sewn-plank boat using materials and tools available to Bronze Age boatbuilders, in an experimental project as defined by Ole Crumlin-Pedersen (1995). Probably the most experienced experimental maritime archaeologist of recent decades, Crumlin-Pedersen (1995; 2006b: 3) recognized that experimental projects have to bridge the gap between natural sciences and the arts. In this, he explicitly rejected an exclusively quantitative or 'scientific' approach, modelled on the positivism of the natural sciences, and advocated by John Coates and colleagues (Coates *et al*., 1995). Even though there are a number of similarities between the two approaches, the fundamental difference is that the positivist approach examines principally the completed stages or phases through the testing of explicit hypotheses (for example McGrail, 2006: 11), whereas the approach advocated by Crumlin-Pedersen (1995; 2006b) places the emphasis of the experiment on what can be learned from the process of building the reconstructions (see also Ravn *et al*., 2011 for a critical comparison between the two approaches). Very much in keeping with Crumlin-Pedersen's philosophy, the experimental construction of *Morgawr* was designed as a 'dialogue' between an archaeologist (or archaeologists) and a shipwright.

Crumlin-Pedersen (1995: 304) defined five characteristics of such a project which were adhered to, as far as was feasible, in the construction of *Morgawr:* 1) an archaeological base in substantial remains of an ancient vessel, documented to a rigorous standard; 2) a research strategy for the analysis of the potentials of the find; 3) a group of craftsmen and sailors with relevant skills; 4) documentation of the aims and the outcome of the experimental activity; 5) publication in relevant contexts and media.

The archaeological basis

The archaeological basis for the project are the finds from the foreshore of the Humber estuary, immediately southeast of the village of North Ferriby in East Yorkshire, and documented to a high standard but not, admittedly, quite as rigorous as those in force today (Wright and Wright, 1939; 1947; Wright, 1976; 1985; 1990). In September and October 1937, Ted and his brother Claud ('Willy') Wright discovered the remains of Ferriby 1, which were progressively exposed in the following years, and in October 1946 the remains were removed to the National Maritime Museum at Greenwich. Ferriby 1 comprises a composite keelplank with bow and stern halves, two outer bottom-planks and a part of a lower strake, all made of oak. The keelplank and outer bottom-planks were connected through a system of integral cleats and transverse timbers, and were sewn together using yew withies. So-called 'independent slots' were thought to be the location of frames (consistently called 'ribs' in Wright, 1990). Both outer bottom-planks had cracked and had been repaired using yew withy stiches. Common hair moss (*Polytrichum commune*) twisted into cords provided the caulking. The *in situ* overall length was 13.32 m and the maximum breadth 1.67 m. These finds are considered to be 'dimensionally stable' (Crumlin-Pedersen and McGrail, 2006: 53). A number of field drawings ('measured field sketches'; Wright, 1985: 138) and photographs were made in the period 1937–1946, but the first measured plan, profile and section drawings, and photographs of the complete find were not made until a period between October 1946 and January 1947, by which time the boat comprised 52 'major timbers' (Wright, 1990: 36–7). The find was published in co-authored papers by Willie and Ted Wright (1939; 1947), and later with additional interpretations by Ted Wright (1976; 1985; 1990). Very little timber remains of Ferriby 1, with the majority being discarded after attempts to conserve the craft failed (Coates, 2005: 38).

The remains of Ferriby 2 were discovered in November 1940, and partly revealed in the following months and in April 1942, with field drawings and photographs made on each occasion. Ferriby 2 comprises a composite keelplank of oak with bow and stern halves. Both halves included the remains of integral cleats and transverse timbers and 'independent slots'. The caulking between the planks was of common hair moss. The total *in situ* length was 11.4 m and maximum breadth 0.80 m. It too was removed in October 1946 and reassembled in Greenwich, were measured plans, profile and section drawings, and photographs were made. The find was published in co-authored papers by Willy and Ted Wright (1939; 1947), and later with additional interpretations by Ted Wright (1976; 1985; 1990). As was the case for Ferriby 1, the physical remains of Ferriby 2 have been largely discarded (Coates, 2005: 38).

Ferriby 3 was discovered in March 1963 and excavated the following month, when measured field sketches were made. Ferriby 3 comprises part of an outer bottom-plank, 7.7 m long, stitched with yew withies to the corresponding fragment of the lowest side-strake, 5.67 m long, both cut from oak. The wood was lifted in April of that year and transported to Hull Museum, where it was measured and converted to plan, profile and section drawings. The find was published by Ted Wright (1976). The preserved remains of Ferriby 3 are held by the Hull and East Yorkshire Museum.

Ferriby 4, discovered in 1984, is a *c.*1.0 m-long fragment of alder which has been interpreted as a rail or washstrake. A cut-out may have been an opening for a thwart and a vertical hole may have provided anchorage for the top of a frame; the function of a horizontal hole was not established. The timber dates to 800–200 cal BC (530–375 uncal BC, at one sigma confidence) and is therefore of Iron Age date (Switsur and Wright, 1989). The find was published by Ted Wright *et al.* (1989). McGrail has rejected the identification of this worked piece of wood as being part of a sewn-plank boat, because the timber did not have any sewn-plank-boat characteristics, and alder is not known to be a genus used in prehistoric boatbuilding (2001: 187). Ferriby 4 is mentioned here because the fragment was incorporated in the 'complete boat' by Ted Wright and John Coates.

A recent programme of dating the remains of Ferriby 1, 2 and 3, coupled with the removal of the contaminants that had been applied to the remains in the (largely failed) attempts to conserve the timbers, has sought to provide accurate dates for these vessels. This programme produced the new dates listed in Table 1 (Wright *et al.*, 2001).

Analysis

The first reconstruction of Ferriby 1, presented in Willy and Ted Wright's paper of 1939 (351: fig. 3), shows a craft with a rounded hull in cross section. The error of this interpretation was recognized in 1946 with the exposure of a complete set of cleats and transverse timbers, which established beyond doubt that the purpose of this framing system was to maintain flatness across the three bottom-planks: the keelplank and the two outer bottom-planks either side (Wright and Wright, 1947: 119; Wright, 1985: 107). This finding was reinforced with the discovery of Ferriby 3, which provided additional evidence that the boats were not rounded but hard-chined. The transverse flatness of the bottom structure of the Ferriby boats has been accepted by most commentators. However, Owain Roberts (1992) suggested that a similar but more extensive set of cleats and transverse timbers across the five planks of the Brigg 'raft' was used to provide it with a rounded hull in cross section, but this suggestion has not gone unchallenged (for example McGrail, 1994; 2001: 187; 2014: 177). McGrail (1994) adds that the frame shape also helped to prevent over-run when beaching which would clearly stress the stitches and to help realign the planks after seasonal dismantling for hull reassembly.

The issue of the shape of the boat longitudinally, fore-and-aft, has been a matter for extensive debate. The first field sketch of the profile of the boat (Wright and Wright, 1939: 351, fig. 1) shows a single curved line representing the lengthwise profile of Ferriby 1 *in situ*. This drawing was based on the initial *in situ* recording of the full length of the boat in 1937, with the two ends exposed and the depth of the keelplank measured with the use of a pointed stick. It shows that the centre of the boat was the lowest point and leaves little doubt that the boat was curved longitudinally (Wright, 1990: 7–8). When Ferriby 1 was reassembled at the National Maritime Museum in Greenwich in 1946–7, it comprised 52 fragments of 'major timbers' (Wright, 1990: 36–7, fig. 2.16), which, at that point, appeared to represent a craft that was flat-bottomed both transversely and longitudinally. Only at this point were the detailed plans, elevations and section drawings produced. Based on these drawings, Ferriby 1 and 2 were shown as flat-bottomed craft in both planes (Wright and Wright, 1947; Wright 1976). The reconstruction (No 1) of Ferriby 1 (produced by Ted Wright in 1946 and published in 1947), a 1:8 scale model of the surviving archaeological remains presented to Hull Museum (made by Ted Wright in 1947), and the models in the National Maritime Museum in Greenwich reflect this interpretation of the boat (Wright, 1990: 86–7).

This analysis and interpretation of Ferriby 1 remained generally accepted until the 1980s, when Ted Wright decided to re-examine the evidence in response to the production of an exhibit of Ferriby 1 for the National Maritime Museum (Wright, 1990: 90). As he has described in considerable detail (Wright, 1985; 1990: 85–95), using the original field-sketches and a number of the photographs from the 1930s and 40s (for example Wright, 1990: 25, figure 2.3; 26 figure 2.4; 30, figure 2.8), Ted Wright changed his mind about the shape of the boat lengthwise, advocating his new understanding that it was curved fore-and-aft and with rockered keelplanks. Reflecting this, he produced a new reconstruction sketch in 1988 (Wright, 1990: 86, fig. 5.2).

His re-examination formed the basis of the reconstruction drawings and accompanying text of the 'complete boat' he produced with John Coates (in Wright, 1990: 85–116) (Fig. 2a) and he declared 'the hypothetical reconstruction of a complete boat [is] . . . in sufficient detail for actual building to be undertaken and to estimate its performance' (Wright, 1990: xv). The 'complete boat' effectively incorporates the evidence from Ferriby 1, 2, 3 and the washstrake of the Iron Age-period Ferriby 4 into a single craft, although this accepts that large sections, particularly of the upper hull, are not represented in any of the Ferriby boat finds. It has an overall length of 15.90 m, a maximum beam of 2.52 m, and is rockered, with the ends 1.32 m higher than the underside of the keelplank amidships. The main features of the 'complete boat' are an equal-ended hull, three strakes on each side with joined planks, thwarts for structural integrity and as seats/ cross beams for the paddlers, frames in the 'independent slots', and girth-lashings and inserted boards at both ends (Wright, 1990: 112–3, table 5.1). In general terms, Crumlin-Pedersen and McGrail (2006: 54) caution against 'the possibility . . . that naval architects, knowing the ensuing advantages to the boat, may instinctively incorporate a longitudinally curved, rockered bottom to their reconstructions' but in the case of Ferriby 1 and 2, a straight bottom line would be incompatible with the archaeological evidence from the very first *in situ* recording of the full length of the boat in 1937, as detailed in the previous paragraph.

The authenticity of the 'complete boat' has since become a matter of a discourse principally mapped out in the papers of this journal. McGrail (for example 2001: 186–7; 2007) has consistently argued that the 'complete boat' is not a minimum reconstruction of Ferriby 1, nor should the alternative reconstructions—made at various scales over the decades—be summarily dismissed. He maintains that a full reinvestigation of the archives of Ted Wright and the remaining fragments of Ferriby 1 should be undertaken as a first step in the critical evaluation of the 'complete boat'. John Coates (2005) has defended the design and details of the 'complete boat', as well as its seafaring capabilities. In preparation for the redating of the Ferriby 1, 2 and 3 boats (cf. Wright *et al*., 2001), the full collection of remains of these craft were examined at the Hull and East Riding Museum. While sufficient material remained for a programme of radiocarbon assays, and details such as cleats were still identifiable, the fragmentary nature of these remains precluded any new analysis that would provide the conclusive new insights McGrail has asked to gain from a full reinvestigation of the boat remains.

Roberts has also raised a number of questions on the 'complete boat'. He argues for a rockered craft with more rounded ends as these may have flattened after deposition, noting that the ends of the Dover Boat had become flatter after its deposition in the River Dour; and for a different system of framing, noting that the later Dover Boat lacked full framing from sheer to sheer (2006: 37).

The construction and design of *Morgawr* was discussed at an experts meeting held on 10 March 2012. This included the project staff, the newly appointed shipwright Brian Cumby, and several independent and unbiased experts in the field, notably Peter Clark, Peter Marsden, and Christer Westerdahl. Accepting that further investigation of the physical remains of the Ferriby boats would not provide new and incontrovertible evidence of the shape and size of the boat, that the earliest evidence indicates that Ferriby 1 was longitudinally curved, that the upper hull sections of the 'complete boat' are based on considerably less direct archaeological evidence than the lower hull section, and that *Oakleaf* had been successfully built at half-scale using the 'complete boat' design, the expert meeting agreed that the 'complete boat' would provide the default design for *Morgawr*, with any deviation from the reconstruction drawing to be recorded and explained. Other key decisions from this meeting were: 1) The keelplank was to consist of two parts made from a single tree, which would be sawn rather than split, because the risk of not producing the required halves for the keelplank was too great, and limited budgets did not allow for a second attempt; depending on the length of the tree that was to provide the keelplank, the scarf-joint could be positioned more towards midships than was the case in Ferriby 1, where the joint was closer to the stem. 2) The lines of the craft would be evaluated by the shipwright as the work progressed and temporary frames or battens employed, which were to determine the shape of the craft, would be based on the 'complete boat', with any deviation recorded and explained. 3) Scale models would not be produced, but the half-scale *Oakleaf* (Gifford and Gifford, 2004; Gifford *et al*., 2006) was studied as part of the design process. 4) It was agreed that the single half-hitch knot was sufficient to tie the yew withies; experience with twisting yew into withies had shown that this was relatively straightforward and that one could twist the yew strands on the tree if desired; withies had to go three times through the holes and, as experienced in the reconstruction of the Dover Boat, the best way to achieve the desired result was to insert the thickest part of the withy and tie the tapered end (Goodburn, 2004: 140). 5) It was agreed that the moss used for caulking would be mixed with tallow. The tallow was required to prevent the moss from drying out before the launch. While it was acknowledged that there is no archaeological evidence for the use of tallow in any of the Bronze Age sewn-plank boats, if tallow (or other lipid substances) had been used in the caulking of prehistoric boats, it would have been washed out and removed from the archaeological record; 6) It was agreed that all additions, such as the thwarts and the use of tallow, had to be 'within the technological envelope of the original vessel, and must be usable in the role proposed for the vessel' (Crumlin-Pedersen and McGrail, 2006: 55).

Morgawr is a 'minimum reconstruction' as defined by Crumlin-Pedersen and McGrail, insofar as it incorporated 'minimalistic ways to complete the hull and point to the most likely means of propulsion and steering for the vessel' (2006: 57), and using the archaeological evidence of the Ferriby boats and the paddles from the same foreshore. From the outset of the construction, we accepted that alternative reconstructions could be equally valid. Taking all these design issues in consideration, *Morgawr* is most aptly referred to as a 'floating hypothesis' (McGrail, 1992: 354).

Craftsmen with relevant skills
Morgawr was constructed under the direction of the shipwright Brian Cumby, who has more than 30 years' experience of building wooden craft and had been involved in a number of reconstruction projects. Over a period of three months, the shipwright was trained at the University of Exeter in the use of Bronze Age tools and technology, the principles of experimental archaeology, and the design of Bronze Age sewn-plank boats.

The actual building of the boat was undertaken by some 100 volunteers, both men and women, whose ages ranged from late teens to octogenarians (Fig. 3). The volunteers came from very different walks of life, but the majority were students, in archaeology or fine art, and retirees. The latter group represented a variety of professions, including boatbuilders, engineers, management consultants and sailors. During the project, an 'apprentice' (Tom Monrad Hansen) was appointed to support the shipwright in his daily tasks and take responsibility for the stitching. Overseeing the project lay with archaeologists from the Universities of Exeter and Southampton with expertise in maritime archaeology, experimental archaeology and the Bronze Age, and staff of the NMMC.

The shipwright worked with volunteers to construct the boat inside the NMMC, in full view of the public. Particular conditions the shipwright had to deal with, and which have no parallel in the Bronze Age, included: the high cost of the timber which meant that the oak boles, once selected, could not be rejected if these turned out to be less-than-ideally suited for the project; the workshop environment, the heating which caused the timber to shrink and split, and the solid concrete floor that prohibited the use of dug-in supports as part of the construction process; and a planned deadline of six months for the construction of the boat—which proved to be unrealistic.

Figure 3. Volunteers working on *Morgawr's* keelplank. (Photo: Robert Van de Noort)

Documentation
One aim of the project was to test the feasibility of constructing a sewn-plank boat using Bronze Age technology and replica tools. Following Crumlin-Pedersen's (1995) philosophy, the project was to gain new insights into the design of the boat through a dialogue between the shipwright and archaeologists. Specific questions that were to be answered were: What are the strengths, characteristics and limitations of using (replica) bronze tools in the construction of the boat? Can the boat be carved to the required shape using bronze axes and adzes from the half-boles, without employing steam-and-bending techniques? How effective is the system of integral cleats and transverse timbers in ensuring stiffness of the bottom of the hull? Are yew withies strong enough to hold all the planks in place? How effective is moss caulking in making the boat watertight? What compromises and changes did the shipwright determine in the process of constructing the boat? Why and how did these affect the shape of the finished boat compared to the 'complete boat'?

Acknowledging that 'recording the experience gained in the construction project is a continuous process, in contrast to an isolated test of a preconceived hypothesis' (Crumlin-Pedersen, 1995: 305), the documentation of the outcomes of the experimental activity reflected this idea. Thus, alongside the production of a set of archaeological plans of the completed craft, structured interviews of the shipwright and the volunteers who helped to build the boat and analysis of the tools at the beginning and end of the project, the dynamic process was documented through the use of a daily log of steps taken and decisions made kept by the shipwright, time-lapse photography which provides a continuous record of the construction of *Morgawr*, digital filming throughout the project, and 3D laser scanning of the boat at various stages of its construction.

Publication
The principle publication on the construction of a Bronze Age-type boat is presented in the current paper; the ongoing and future seatrials will be reported in a future publication. During the construction period, social media, such as Facebook and YouTube were used to place large numbers of images of the project in the public domain (all electronic data produced during this project is stored at Open Research Exeter: http://hdl.handle.net/10871/14703). A 40-minute feature film is made publicly available on the Vimeo website (http://vimeo.com/76346352). The use of these new media ensures that information on the construction of *Morgawr* is widely disseminated.

Building *Morgawr*

The construction process commenced in April 2012 and was completed in March 2013. Squaring the

Figure 4. The completed central keelplank. (Photo: Jon Bennett)

halved-logs was completed by the end of May 2012. Carving the two halves of the keelplank was accomplished towards the end of July, and the cleats had been carved from the keelplank by early September (Fig. 4). Work then commenced on the two outer bottom-planks, and in early October these were complete and where stitched to the keelplank using yew withies. The frames were loosely fitted to act as guides for the construction of the side-strakes, and these were carved and stitched during the following months. The washstrake was finally added in early March 2013.

In order to build our floating hypothesis as close to the 'complete boat' as possible, its cross-sectional shape was essentially derived from patterns, or moulds, of plywood that were made on the basis of plans of the 'complete boat', and on occasion adjusted. Pine battens were then fixed to the plywood cross-sections at the height of the seams of the side-strakes. Based on this, the frames and planks were cut and adzed to the required size and shape (Fig. 5). This meant that *Morgawr* was build 'off plan', at least in the early stages of the project. As such, and as noted with the use of temporary frames as guides, *Morgawr* was not built entirely in the plank-first mode as the original Bronze Age vessel is thought to have been.

Timber

The boles of three English oaks (*Quercus robur*), totalling 20 tonnes in gross weight, were acquired from Summerscales Sawmill in Keelby, Lincolnshire, just 10 km south of the Humber. The boles were greenwood, having been cut less than six months before the start of the construction. One had been sawn lengthwise in halves and these formed the bow and stern keelplanks. A second tree-trunk was obtained whole with the intention of cleaving it, but, after several failed attempts to obtain straight planks from this twisted trunk, it was decided to have it sawn. The third tree

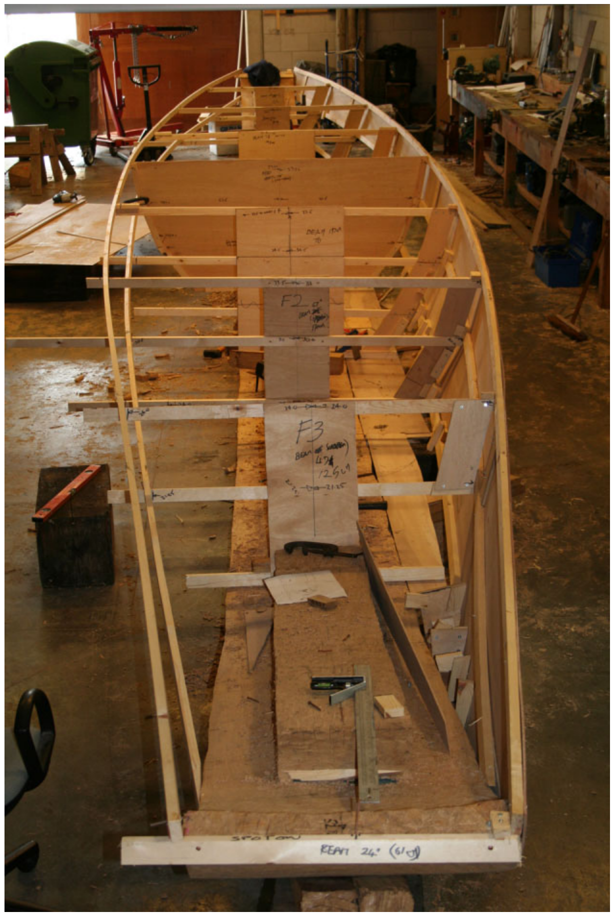

Figure 5. Using battens and temporary frames to determine the shape of *Morgawr.* (Photo: Robert Van de Noort)

was delivered sawn in planks that could be used as rough-outs of planks for the boat. Sawn timbers are notionally weaker than cleaved timbers because of the severing of fibres, but because of the thickness of the finished planks at 0.07 m, to date no noticeable weaknesses have been detected.

Initially, all carpentry was undertaken with Bronze Age replica axes and adzes of bronze. Wooden wedges were used to remove large amounts of excess timber. However, this turned out to be something of a false economy, as the resultant uneven surfaces were very difficult to work with bronze tools. As deadlines neared we chose to employ modern tools to produce the rough-outs of planks; however, all planks were carved or sculpted into shape using bronze tools. We considered that steaming these planks, all at least 0.07 m thick, was simply not possible using the Bronze Age technologies of open fires or 'hot rocks'. In this context, it is noteworthy that for the construction of *Oakleaf,* the half-scale reconstruction of the 'complete boat', planks were bent following steaming. However, this was accomplished by placing the planks inside a PVC sleeve at a temperature of 70° C for three hours before they were bent into shape; a full-scale plank would have to be kept at such a temperature for six hours or more before it could have been bent into shape (Gifford *et al*., 2006: 58). Without the use of PVC sleeves, such a task could not have been accomplished.

Timbers for the frames, comprising two crooks each, were obtained from a local sawmill and were loosely fitted once the keelplank and outer bottom-planks had been sewn together. The frames were used to keep the side-strakes in position before they were sewn to the assembled bottom-planks. This may not have been necessary if *Morgawr* had been built on a beach where the unfitted strakes could have been supported by external posts or stakes (for example Goodburn, 2004: 156–7).

Tools

At the time Ferriby 1, 2 and 3 were constructed, the only bronze axes available in Britain were flat axes. Complete and intact toolmarks on the archaeological remains of the Ferriby boats are rare. Indeed, the few intact axe facets on Ferriby 1 were only 25 mm wide, and those from Ferriby 2 were just over 70 mm wide (Wright, 1990: 40, 135). The former cannot have been made with an Early Bronze Age flat axe, and either a smaller implement was used or, alternatively, the measured toolmark did not display the full width of the axe because one or both side features had been erased by subsequent cuts (see Sands, 1997: 11–13).

The bronze tools (88% copper and 12% tin, as was commonly used in the Bronze Age) for the construction of *Morgawr* were produced by experienced bronze-toolmaker Neil Burridge, and the complete Aylesford-type toolkit included nine axes and nine adzes (with blade widths of 70 or 50 mm), and nine chisels or very narrow axes (with blade widths of 20 mm) (Fig. 6). Bronze flat axes of the Aylesford type were the most common in East Yorkshire at the time Ferriby 1, 2 and 3 were built (Manby *et al*., 2003: 62–3). The axe and adze blades were individually cast in hot stone moulds. The castings were quickly cooled and quenched in cold water, going from molten to cold in *c.*10 seconds, keeping the bronze ductile to allow for longer forging periods. The blade edges were hammered for around 10 minutes before final grinding, polishing and sharpening. The blades were then fitted to ash handles with leather lashings. The blades were mounted within a metal collar, and in some cases modern glue, to reduce the amount of time spent rehafting blades. This was considered necessary because the inevitable frequent rehafting required when using traditionally mounted tools would slow down the progress of construction. Some other compromises were reached. The shipwright requested some long-handled axes and adzes, which enabled him and the volunteers to lock the top of the shaft into their hips, so that the working action was controlled and involved more of the body (Goodburn, 2004: 129). As hand tools would be used constantly over weeks and months, it was important to reduce potential strains and ensure comfortable working positions of tool and

Figure 6. Assemblage of the tools used in the project. (Photo: Robert Van de Noort)

Table 2. *Tools at the end of project by type of head and haft (numbers in second and third column refer to individual tools)*

Bronze tool head shape	Long handled	Short handled	Total	Total
Flared axe	1, 25, 26 (decorated)	—	3	—
Axe	—	8, 7, 23, 24, 9 (on display)	5	Axes 8
Flared adze	16, 17, 18, 19	2 (cut down from long)	5	—
Adze	—	10, 20 (missing), 21	3	Adzes 8
Broad chisel	—	C2, C3, C4, C5, C6	5	—
Narrow chisel	—	C1, C7, C8, C9	4	Chisels 9

body (see Darrah, 2004: 167). For the same reason, the heads of all the tools were enlarged to provide a little extra weight.

The tool performance was assessed by interviews with the volunteers and the shipwright, and through analysis of the tools at the end of the project. Overall, the tools performed very well once the boatbuilders got used to the different motions needed to use them effectively and in a manner which preserved the edge and the haft while working with accurate and well-considered blows, working carefully around knots in the wood. As the construction of *Morgawr* progressed, the various tool categories were aligned with particular tasks. Axes saw most use in the first phase when the trunks were being de-barked and then roughly squared. The adzes came into greater use once the finer squaring of the large trunks started and were used for shaping the planks. Adzes and chisels were used to shape the cleats, and chisels were used to shape the holes. At the end of the project, the toolkit comprised 25 tools (Tables 2 and 3), including two unhafted bronze blades, one blade which was broken near its narrowest part, and remnants of three broken hafts which had been retained. During the project, some bronze pieces that had come out of their hafts were changed into different hafting arrangements, at times changing an axe into an adze. One axe and one adze had gone missing over the life of the project.

Table 3. *Summary of the wear and condition of the tools at the end of the project*

Tool type	Wear recorded
Long axes	The blades are all slightly flared. Lighter use than short axes (as seen by wear on handles) and two out of three have some nicks on the edge.
Short axes	Varied degrees of use, likely related to balance and handle setting. Two had small nicks in the edge and one was also slightly burred.
Long adzes	Two of the four have either small nicks or, in one case, a dent on the edge. All used more heavily than any of the axes.
Short adzes	Two of the three available for study have slightly rolled edges. One (2), the cut down long adze is more lightly used and close inspection and volunteer comments show that this haft is not balanced. The short adzes were the most in demand tool type towards the end of the project. All are used but one has a slightly narrower edge which was commented on as less useful; the favourite of those who expressed an opinion (21) also had the most wear on the handle.
Broad chisels	All had nicks and two of the five had a section of rolled edge. Four had split handles indicating their heavy-duty usage.
Narrow chisels	Two of the three narrow chisels had rolled edges.

Yew withies

The use of yew withy stitches in Bronze Age sewn-plank boats has been a topic for discussion ever since its first identification (for example Wright, 1990: 64; 129–13; Goodburn 2004: 137–42). Previous half-scale reconstructions have had some success in locating suitable yew material and producing stitches, but not until the construction of *Morgawr* have yew withies been used as the only means of fitting planks together in a modern full-scale sewn-plank boat. Yew (*Taxus baccata*) wood is well-known for its excellent tensile qualities and it was the material of choice for bow-making (for example Spindler, 1995; Hageneder, 2007: 101–3). The toxicity of the leaves, seeds and wood of the yew tree makes it highly resistant to decay caused by fungi and insects both in dry and wet environments (Bevan-Jones, 2002: 8–12; Hageneder, 2007: 47–9). Willow and hazel of the same diameter would both be less flexible and durable, and holly does not tend to produce sufficient suitable lengths of material and is also more problematic to harvest because of its serrated leaf edges. The choice of yew withies as stitching materials seems, therefore, wholly pragmatic. Folklore and early historic accounts refer frequently to the rich symbolism of this evergreen tree with its distinctive two-coloured wood and its associations with magic, royalty, churches and wells (Bevan-Jones, 2002: 135–45, 165; Hageneder, 2007: 218–39), and it has been suggested that these magical properties may have been a factor in the selection of yew for the stitching of sewn-plank boats (Helms, 2009: 153).

Yew will coppice but is a slow-growing wood (Oaks and Mills, 2010). Yew withies of suitable size were kindly donated to the project by the National

Arboretum, near Tetbury in Gloucestershire. No matter how much these withies were soaked and twisted, it proved impossible to use this material, and subsequent experience suggests that these withies were simply not fresh enough. Therefore, material was collected from yew trees near Falmouth as and when withies were required. The upright and closely branched Irish yew (*T. baccata* 'Fastigiata') gave the right kind of growth conditions for stitching materials for this project. However, it is fully recognized that this variety did not exist in England before the 18th century AD (Bevan-Jones, 2002: 2), and that other closely related yew varieties with growing conditions favouring long and tall upright growth, would have been used in the Bronze Age. The time of the year that the yew withies were needed for this project was late summer, autumn and then winter, but the limited ethnographic data available suggests that collecting yew withies is best undertaken in the spring (Stewart, 1984: 162). Twisting the withies soon after their harvest, and storing them in water, was found to prolong their usable life. Both twisted and untwisted withies were used on Ferriby 1 (Wright, 1990: 67–8). Experience revealed that the yew withies either needed to be freshly cut or processed very soon after harvesting by twisting the branches to split them longitudinally. The twist needed to be carefully worked along the stem and across any stiffer nodes. A device similar to a basketmaker's 'commander' can be useful for this, and the L-shaped wooden tool found at North Ferriby may have served such a function (Wright, 1990: 155–6).

Withies are the essential element that holds all the finely sculpted but bulky woodwork together, but they constitute the weakest and most vulnerable aspect of the sewn-plank boat. The stitches were countersunk on the bottom of the boat, protecting them during beaching. Though much attention has been paid to the material of the stitches themselves, these can only perform their function with well-made and correctly positioned holes. The stitch-holes had to be made with care, ensuring the absence of sharp corners which would have increased wear on the withies. *Morgawr* has 225 withy stitches and 450 stitch-holes. Those in the bottom of the boat were prepared by chiselling a hole from two directions, working both at the correct angles, and then rounding the hole and rebating the stitching area. Having made some of the holes using traditional methods, they are estimated to take one hour to cut, plus a further 15 minutes or more to smooth and finish each hole. The original holes appear to have been made in this fashion and the finishing would have been important as rough edges would create uneven strains and points of wear, resulting in the failure of the stitch. In round figures this aspect of the work might take some 600 hours to complete. The woodworking skills required for this aspect of the work are care and attention to detail, but not necessarily the highest level of skill or fitness, though accessing the right place and angle can lead to awkward working positions. The withy material was threaded through the prepared pair of holes and the stitch was carefully tightened (Fig. 7). A basketmaker's commander-type device was used to tighten the stitch, by passing the leading-end of the withy through a hole in the commander-type implement and then applying leverage to tighten the withy, before threading another stitch. As the three or four loops were completed and the space was closed, this process became very tricky. The ends were held in place by threading the material back under the stitch. Finally the end was trimmed and the gaps plugged with a wad of moss and tallow, followed by a covering of beeswax (Fig. 8).

Figure 7. Detail of *Morgawr*, showing a finished yew withy stitch, protected with beeswax. Thickness of individual withy is circa 0.01 m. (Photo: Jon Bennett)

Paddles

A set of 20 paddles were made of ash (*Fraxinus excelsior* L.), using G. K. Beulah's copy of the Ferriby paddle found in 1939 (and lent to the NMMC by Hull and East Riding Museum) as a guide. While the tree genus of the 1939 paddle find was never successfully determined, a second paddle found near Ferriby 2 in 1946 was definitely made of ash. The blade of the 1939 paddle measured 0.85 m long, 0.15 m wide and 0.023 m thick. Only 0.2 m of the shaft remained, but the full length of the shaft is believed to be around 1.5 m (Wright, 1990: 151–5). Volunteers who made a paddle were encouraged to make these with a length that suited them individually (Fig. 9), as would almost certainly have been the case in the Bronze Age, and is witnessed in the range of paddle sizes recovered with the Hjortspring vessel (Crumlin-Pedersen and Trakadas, 2003: 119–36).

Morgawr: description of the boat

General description

The final archaeological plans of Morgawr are presented in Fig. 2b. It shows a boat with much finer lines than the 'complete boat'. *Morgawr's* key characteristics, in which it corresponds with the ‘complete boat’, are as follows: 1) The two halves of the keelplank come from a single split trunk with pith down and with the thicker stump-ends outwards and thinner crown-ends towards the scarf, which comprises a simple lap-joint (Fig. 4). The outer bottom-planks were cut from the second bole, which also provided the timber for some of the side-strakes and the transverse timbers. The remaining side-strakes and thwarts were cut from the third tree. The side-strakes were cut from the halved-logs in such a way that the line of the pith faces towards the inside of the boat. The half-frames were sourced separately, from local sources in Cornwall. 2) It has an equal double-ended hull, and the position of features (such as cleats and the ‘independent slots’) along the keel is more-or-less symmetrical. 3) In principle, the plan of planking, frames and cleats is symmetrical. 4) An integral system of cleats and slots and transverse timbers was used to provide stiffness to the bottom of the boat, comprising the keelplanks and outer bottom-planks, but not to the side-strakes (Fig. 10). 5) Frames were inserted in the ‘independent slots’ (Wright, 1990, figure 5.13). 6) The keelplank, outer bottom-planks and the lowest side-strakes had bevelled edges or a rebate to ensure a rigid fit (Fig. 11). 7) Three strakes were fitted each side, outboard of the outer bottom-planks. 8) The side-strakes were butted along the length of the boat in the same manner as the ‘complete boat’. They were positioned where possible at frame stations to provide more integral strength and a degree of protection. They were also staggered longitudinally in order to avoid creating points of weakness. All strakes were secured by lashing around the frame, further highlighting the

Figure 8. Detail of *Morgawr*, showing a countersunk yew withy stitch at the bottom of *Morgawr* before treatment with beeswax. Thickness of individual withy is circa 0.01 m. (Photo: Robert Van de Noort)

Figure 10. Detail of *Morgawr*, showing cleat-system, independent slots with frames fitted, three side-strakes and wash-strake, and thwarts. (Photo: Robert Van de Noort)

Figure 9. One of the 20 paddles, based on the examples based on G. K. Beulah’s copy of the Ferriby paddle found in 1939; length of paddle shown: 1.52 m. (Photo: Robert Van de Noort)

mixed construction approach to the building of *Morgawr*. 9) Yew withies were used for the stitching; some of these were twisted strands of yew, others were stripped yew branches. 10) Woodland mosses were used for caulking.

Significant differences between the 'complete boat' and *Morgawr* are summarized in Table 4 and outlined here: 1) The length of *Morgawr* is 15.28 m, 0.62 m shorter that the 'complete boat'; this was, in equal parts, the result of the need to cut 0.30 m off the stern keelplank because of weaknesses in the timber and the overall length of the bole used for the keel. 2) The maximum beam of *Morgawr* was reduced from 2.52 m in the 'complete boat' to 2.0 m, producing a more longitudinally straight-sided boat which ensured that the paddlers' direction of movement was closely aligned to optimize effective propulsion, and reflecting the shape established for the Dover Boat. 3) *Morgawr's* planks were carved, not bent, into shape as the tension of the planks was far too great for bending using Bronze Age steaming technologies. The girth-lashings and winged cleat shown in the 'complete boat' were therefore deemed redundant and thus omitted. A degree of bending has been proposed for Ferriby 1 (Wright, 1990: 128–9) and the 'complete boat', but no mention is made of the use of the steam-bending method. 4) *Morgawr's* central keelplank extends the entire length of the boat whereas the two outer bottom-planks attached either side of the keelplank are shorter and thus helped facilitate the narrowing and rising of the boat at either end. This is witnessed in both vessels. However, due to available timber length, the outer bottom-planks in *Morgawr* were shorter than the 'complete boat'. This resulted in the subsequent planks being shorter and hence made the lines of *Morgawr* finer. 5) Unlike the 'complete boat', *Morgawr's* side-strakes abut the upturned ends of the keelplank in such a way that the end-grain of the timbers is not exposed, being rabbeted to the keelplank (Fig. 12). 6) *Morgawr's* side-strakes are straighter than those of the 'complete boat', which are shown in the drawing (Wright, 1990: fig. 5.17) with the ends turned down and being connected to the bottom of the boat with three stitches; this alternative design is, in part, the result of building a less-rounded craft. 7) The arrangement and number of extant frame, cleat and transverse timber arrangements was not consistent in the original Ferriby boats, thus in the building of *Morgawr* it was decided that cross timbers would be deployed where considered necessary to add transverse strength. 8) *Morgawr* has an additional (seventh) frame, having a central frame

Figure 11. Detail of *Morgawr* showing bevelled edges or rebate of the keelplank and the central lap-joint. Width of 'independent slot' is 0.12 m. (Photo: Jon Bennett)

Figure 12. Detail of *Morgawr* showing side-strake abutting the upturned end of the keel. (Photo: Robert Van de Noort)

Table 4. *Comparing the measurements of Morgawr with Wright and Coates' 'complete boat'*

	Wright and Coates' 'complete boat'	*Morgawr*
Length overall	15.90 m	15.28 m
Maximum beam	2.52 m	2.00 m
Length:breadth ratio	6.3:1	7.6:1
Height of ends above underside of keelplank amidships	1.32 m	*c.*1.00 m
Height of gunwale amidships	0.98 m	1.00 m
Number of frames	6	7
Floor plan breadth (bottom-planks and keelplank) amidships	1.6 m	1.22 m
Bow to stern cleat arrangement indicates number and associated timber (f = frame; tt = transverse timber)	1(f)-2(tt)-2(f)-1-2(f)-2(tt)-2(tt)-2(f)-1(f)-1(tt)-1(tt)-1(f)	1-2(f)-2(f)-3(tt)-2(f)-2(tt)-2(f)-3(tt)-2(f)-3(tt)-2(f)-2(f)-1

Figure 13. Detail of *Morgawr* showing separate piece of timber added at the base of a frame. Distance between the two sets of yew withy stitching is 0.38 m. (Photo: Jon Bennett)

Figure 14. Detail of *Morgawr* showing the external fixing of one of the thwarts. Length of wedge is 0.18 m. (Photo: Jon Bennett)

placed over the scarf of the keelplank thus adding transverse strength at a point considered to be the weakest part of the construction of the 'complete boat'. 9) All frames were grown crooks; however, a separate piece of timber was invariably added at the end of the half-frames to link them together as the size of available timbers was limited (Fig. 13). 10) All frames in *Morgawr* were lashed into the keelplank and side-strakes; in Wright and Coates' 'complete boat' the frames are held in place by yew withies attached to the side-strakes only, and fixed with a pin to the keelplank (Wright, 1990: 112). The latter solution was considered anachronistic for an early second millennium BC boat, as pins or treenails are not visible on the Ferriby finds or known in Britain before *c.*1100 BC (McGrail, 1978: 333). 11) *Morgawr* was provided with nine thwarts, one next to each frame and two additional thwarts positioned towards midships to provide additional benches or seats, thus increasing the potential number of paddlers; all thwarts were inserted through the top strakes, rather than in between the middle and top strakes as in the 'complete boat', to ensure optimized ergonomic positions for the crew. 12) All thwarts were extended outside the boat and wedged in order to lock them in place; no internal plank notch was used as illustrated in the 'complete boat' (Wright, 1990: fig. 5.16), nor was a beam shelf used to provide support. The wedge prevented the beam thwart from shifting but could be removed, and thus allowed for moveable thwarts which would provide flexibility when loading (Fig. 14). Essentially, the thwarts provided adequate transverse strength and hence the bulk heads at bow and stern were also considered surplus to requirements. 13) Transverse rebates between planks were fashioned in a similar manner to the 'complete boat', however, the specific lashing arrangement differed particularly at the turn of the bilge as they were determined not to be secure (Wright, 1990: fig. 4.8).

No mention is made by Ted Wright of any treatment of the timber and this may not have been considered necessary because Ferriby 1 would have been built outside where a more humid environment and the occasional spring high tide would have kept the timbers wet. *Morgawr's* wood started to show signs of cracking within three months of the start of the project, and a linseed oil-turpentine mixture was used to deal with cracks in the wood. Furthermore, several variations of moss and sheep's tallow were used in sequence and in combination to caulk the joints. Tallow and moss, sometimes supplemented by a small yew peg, were also used to plug the stitch-holes. Finally, beeswax was used to seal the moss-and-tallow mixture. Whereas there is no evidence from any of the Bronze Age sewn-plank boats that tallow and beeswax had been used (see, for example, the analysis of the 'stopping' material in the Dover Boat; Marsden, 2004: 74–5), both substances were readily available and widely used in the Bronze Age, and thus their use in the construction of *Morgawr* was considered justified.

Laser scanning

The boat was scanned on four different occasions to ensure that details that were covered by the addition of planks, frames and strakes were incorporated within the digital model of the boat. Point data was collected on average at a density of 5 mm at 3 m distance, using a Leica HDS 3000 and a Leica HDS 4500. The boat was scanned from various locations around its perimeter ensuring approximately 30% overlap between adjacent scans, culminating in a robust tolerance when matching scans through common pick-points. Registration was then undertaken on the scans using the scanning software's mathematical algorithm to ensure accurate stitching between adjacent scans. Due to the protracted, narrow nature of the boat, the scanner's field of view was restricted to limit the amount of oblique data collected; this, combined with the limited space in the workshop, necessitated that more individual scan positions had to be taken around the structure. Later, scans were taken internally to infill interior

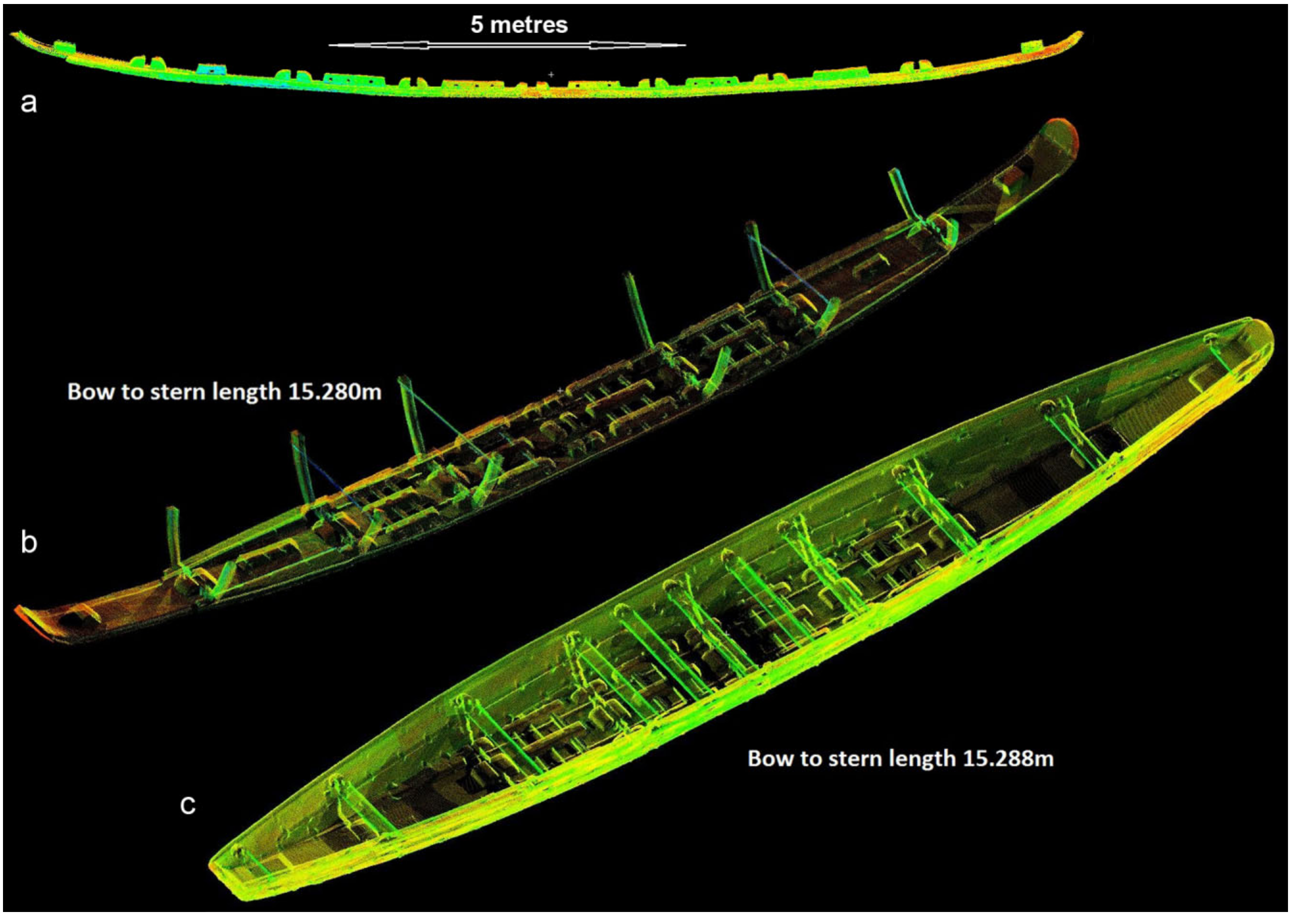

Figure 15. *a)* Longitudinal cross section of *Morgawr's* keel construction on 23 August 2012 showing the degree of rocker; *b)* Isometric view of *Morgawr* construction on 12 November 12 2012, with loosely fitted frames; *c)* Isometric view of the completed *Morgawr* on 4 March 2013. (All images: Andy Wetherelt)

detail. It must be noted that the images of scan data represent 'cleaned' point clouds where all extraneous data has been removed.

On 23 August 2012, a survey scan was undertaken at a point in the construction of *Morgawr* when the keel-plank was a single structure, and a sense of scale could be gathered. The arc between the centre, bow and stern had become a prominent feature (Fig. 15a). This model is based on five scans and details the intricacies of the hand-carved notches and conduits ('independent slots') running perpendicularly through the keelplank that would later house the cross members.

A subsequent scan was conducted in mid November 2012. The bottom of the boat was complete and the cross members fitted, additionally the rounded bow and stern extension keelplank blocks were present in this phase. The overall shape and beam of the boat are clearly depicted in the isometric view (Fig. 15b). Each scan data point has a unique set of 3D coordinates; consequently distances can be deduced and measured from the scan data. The measurement of 15.28 m is an accurate boat length from bow to stern. The discrepancy with the plan of the boat of 0.04 m (see below) is most likely the result of the subsequent flexing of the keel, but possibly includes a small error in measurement, which is not without precedent over such a distance.

The final set of scans, 15 in total, was completed in the courtyard area of the NMMC on the 4 March 2013. This date was chosen to ensure absolute data collection of the finished boat prior to its launch on the 6 March 2013. Registration quality for this final dataset was commensurate with all previous models. Measurements were taken from the point-cloud data and showed an overall length extension of 8 mm from the modelled data of mid November 2012. This is consistent with the boatbuilder's account of the structure flexing during the final build phase. The isometric view with its bow to stern measurement is shown in Figure 15c.

Launch and initial trials

Morgawr was successfully launched on 6 March 2013. Despite initially taking on substantial quantities of water, as had been expected, two short trips were

Figure 16. *Morgawr* returning after its first trial in Falmouth Harbour. (Photo: Jane Cartledge)

undertaken in Falmouth Harbour on the launch day, with *Morgawr* being manned by the volunteers who had built it. Over the course of the next few months a number of trial voyages were undertaken in Falmouth Harbour (Fig. 16). The dry 5.5 ton vessel became a full 7 ton craft (estimated) once she had taken up water, and presented a challenge to manoeuvre and control. The learning curve was steep. The crew was largely drawn from Helford River Gig Club with experienced paddlers added. Courses were set and the first measurements and observations of speed and manoeuvrability were taken. Performance slowly improved and our skill and knowledge increased with each trial. Each trip presented a series of challenges, including paddling in unison, maintaining a straight course with the wind across the bow, and establishing integral stability and balance. Having gained confidence that the boat can be put through a series of rigorous tests, plans are now being developed for systematic trials to be undertaken in 2014 involving a team of experienced paddlers that can take the boat out to sea in different weather conditions.

Reflections and discussion

This project adopted Ole Crumlin-Pedersen's (1995) philosophy of gaining new understanding from building reconstructions based on the archaeological evidence. The fact that *Morgawr* had to be built 'off plan' to ensure close resemblance to the 'complete boat' presents the biggest challenge of a project of this nature. The accepted view with respect to Bronze Age sewn-plank boats was that they were constructed 'by eye' in the shell- or plank-first method (McGrail, 2001: 190). However, as illustrated above, this approach to construction has been compromised in the building of *Morgawr*. As the shipwright himself stated, under the circumstances of this experiment 'you could not have built the boat shell-first'.

The challenge of building an exact copy of an original vessel that was built plank-first, while maintaining control of hull shape, is not new to experimental boat archaeologists (Crumlin-Pedersen, 1996: 115; McGrail, 2006: 14). However, it continues to raise interesting issues concerning the principles of plank-first construction and how Bronze Age boatbuilders, and indeed builders for generations afterwards, actually achieved construction 'by eye' (McGrail *et al.*, 2003: 238–9; McGrail, 2006: 14). What practical constraints did they face and what measures might they have employed to determine the shape of the boat? In reference to the construction of *Morgawr's* keelplank and the available materials that determined the size of the attached outer bottom-planks, the shipwright is quoted as saying that he 'had to work with what he had'. This highlights another of the challenges of experimental archaeology. In this case, 'what we had', ignoring all other constraining factors, was a set of plans; plans that were based on incomplete archaeological finds that no longer existed for reference. In order to ensure *Morgawr* closely resembled the plank-first constructed boat shape of the 'complete boat' the shipwright had no choice but to transfer cross-sectional 'shapes' scaled-up from these plans using a series of plywood patterns (moulds). These patterns thus provided a transverse frame around which the planks were moulded; frames that, in the initial process, helped determine the shape of the boat, and frames that, literally, in the words of the shipwright the ‘planks were sewn onto’. Thus, the boat emerged in the only way it could have done, as a frame-first vessel, a construction approach usually associated with vessels of a much later date. The shipwright followed the plank-first sequence of construction as best he could in respect of his Bronze Age predecessors, but unlike his Bronze Age counterpart he had no direct experience of building plank-first sewn-plank boats and was ‘constrained’ by the experiment and reliant on the plans of the ‘complete boat’ to guide him. His experience was predominantly as a frame-first shipwright and he translated his skills of building ‘by eye’ differently, by employing different techniques and skill sets to meet these new challenges.

So how does this experience inform on Bronze Age boat construction? *Morgawr,* we believe, is akin to a Bronze Age boat, the construction principles are the same, sewn planks, as is the overall shape and scale of the boat. In this respect it is a ‘floating hypothesis’ of a Bronze Age-type sewn-plank boat; however, *Morgawr* was not built entirely plank-first, some guidance was derived from frames or transverse patterns or moulds. Can this observation therefore have implications for our understanding of the boatbuilding processes employed by Bronze Age boatbuilders and perhaps also the archaeological definition of terms such as ‘shell- or plank-first’ and ‘by eye’? In the building of *Morgawr* patterns or temporary frames derived from the plan of the ‘complete boat’ were used and then removed. They acted as guides providing the transverse shape of the hull. Such aids to building are largely invisible in the archaeological record; essentially if used they would have been removed as part of the building process, or no longer visible at the point of deposition when the archaeologists usually encounter boat remains. However, this does not deny their existence or their potential usefulness as boatbuilding aids. When undertaking the building of a series of sewn-plank boats in the Bronze Age, would the boatbuilder have conceived each boat individually ‘by eye’, or perhaps after honing his skill, would he have ‘taken the shape’ from a previously successfully constructed boat and applied it to the next boatbuild through the use of patterns as a guide to transfer the shape? Such applications present both practical and logical solutions as aids to the boatbuilding process, and, despite the fact that they remain largely invisible in the archaeological record, there is no reason why aids or patterns could not have also been used in the Bronze Age. Could it be that plank-first building is in fact the result or the product of the first phase of building prior to the insertion of the permanent frames, rather than the process of building itself, thus, being a conceptual rather than a literal plank-first build? These ideas require further investigation through archaeological, experimental and ethnographic inquiry.

In the process of building *Morgawr*, a number of new insights have been gained, which are summarized here. In terms of the strengths, characteristics and limitations of using (replica) bronze tools in the construction of the boat, we concluded that the axes and adzes performed very well, showing only minimal damage at the end of the project. The handles were evidently the weak part of the tool, and this was aggravated by using them with too much force. Axes were predominantly used in the early stages of the project when planks were cut to size, but the adzes were the tool of choice for fashioning the planks. As for giving the boat rocker, by carving the required shape using bronze axes and adzes from the half-boles, this turned out to be a straightforward activity, and there was no need for using steam-bending techniques. The system of integral cleats and transverse timbers in ensuring stiffness of the bottom of the hull has been proven effective—following the launch only minimal movement of the keelplank and outer bottom-planks has been discernible. It is difficult to imagine that this system could have been used for a Bronze Age sewn-plank boat with a transversely rounded hull shape (see Roberts, 1992; 1995; McGrail, 1994). The yew withies proved to be very strong indeed, providing sufficient strength to hold all planks in place both during the construction of *Morgawr* and following its launch. Finally, the moss caulking has proven effective in making the boat watertight for the seams that are permanently below the waterline; however, for the seams that are exposed above the waterline, shrinkage of the timbers exposes the moss, resulting in desiccation. Only where the seams were covered with a water-resistant substance, such as beeswax, could the moss retain its function.

Conclusion

We have been careful to describe *Morgawr* not simply as a replica of Ferriby-1 (as has been done in the case of *Oakleaf*), but as a ‘floating hypothesis’ of a Bronze Age-type sewn-plank boat based on the Ferriby boats, using Ted Wright and John Coates’ description and published drawings of the ‘complete boat’ as a starting point, noting that this is itself a compilation of the remains of four different craft and that the resulting design has been disputed. The bottom structure of *Morgawr* closely resembles Ferriby 1 and the ‘complete craft’. The main exception is the additional frame, placed over the keelplank scarf for added strength in what is the boat’s weakest point. *Morgawr’s* sides, however, are hard-chined, straighter and possibly stronger, and show a more straight-sided craft.

Reflecting on the Bronze Age shipbuilding technology, the bronze tools and especially the adzes worked extremely well in shaping or sculpting the timbers, and individual volunteers left distinguishable marks on the timber. Very few tool marks survived intact on the archaeological remains of the Ferriby boats (Wright, 1990: 38), and individual toolmarks which could have provided evidence of the number of axes employed in their construction were not recorded. The planks flexed a little, but could not be bent to the extent implied by Ted Wright and John Coates. As we considered that the planks were far too thick for steam-bending using Bronze Age technologies such as open fires or 'hot rocks', the only remaining option was to carve the three-dimensional shapes by chipping away excess timber with bronze adzes and axes. In building *Morgawr* we used patterns to ensure that the boat would closely resemble the 'complete boat', or at least provide a control to know what changes were introduced. Whether the Bronze Age shipwright used a similar technique is not known, but it is unlikely if applying the plank-first principle. Following its launch, *Morgawr* has proven to be a reliable if awkward boat to handle, being extremely heavy and unwieldy but improving as our handling skills improved. Of course, there would have been fewer requirements for a craft in the Early Bronze Age to be steered accurately, as harbours would have been natural beaches and salt marshes, taking advantage of tidal movement to navigate between land and sea without the requirement of jetties. Future trials will include tests on speed, manoeuvrability and handling, and how *Morgawr* behaves under different conditions of swell.

This paper highlights the process and challenges involved in building a 'floating hypothesis' and has sought to demonstrate the important contribution this experiment has made to our understanding of Bronze Age-type sewn-plank boat construction. However, it is clear that this is the start of a dialogue and that *Morgawr* only begins to provide archaeologists with an initial insight into the mind of, and the choices faced by, the Bronze Age boatbuilder.

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